ROORKEE TREATISE ON CIVIL ENGINEERING.

SECTION II.

MASONRY.

EIGHTH EDITION.

REVISED BY

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PREFACE TO THE 1918 EDITION OF SECTION II—MASONRY.

This section has been entirely rewritten and brought up to date. New chapters have been added on Plant and Scaffolding, Concrete, Pointing and Plaster. Appendices have also been added regarding mortars and specifications for different kinds of works.

Chapter VI—" Masonry works in foundation and wells," merely deals with the general question ; details of complicated foundations are given in Section VII—Bridges.

I wish to thank Messrs. Darley and Stampe, Executive Engineers, for the useful suggestions which they have made in certain chapters which they have examined.

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ROORKEE TREATISE.

Section II.—MASONRY.

CHAPTER I.

DEFINITIONS AND PRELIMINARY OPERATIONS.

1. **Masonry** is the art of raising structures in stone or brick.

Masonry is classified either from the nature of the material, as Stone or Brick Masonry; or from the manner in which the material is prepared, as Cut Stone or Ashlar Masonry, Rubble Masonry, Cyclopean Masonry Concrete, Plum Concrete, Reinforced Concrete, etc. And in India there are also *pukka*, *kachcha-pukka*, or *kachcha* stone or brick masonry; *pukka* consists of burnt bricks or good stone laid in lime mortar; *kachcha-pukka* of burnt bricks or stone laid in mud, and *kachcha* of sun-dried bricks laid in mud.

In England the word masonry is seldom used in as broad a sense as it is in India: for there it refers only to structures built with stone while those built with bricks are called brickwork, and a mixture of small pieces of broken brick or stone with mortar is known as concrete.

2. **Definitions of terms used in masonry:—**

Face and Facing.—The front or outside of a wall or structure is called the Face and the materials which form it are called the Facing.

Back and Backing.—The inside of a wall or structure is called the Back, and the materials which form it are called the Backing.

Filling is the interior portion of the work between the Facing and the Backing.

Bed or build.—The lower surfaces of the stones or bricks of each course are termed the *bed or builds*.

In stones the bed is always parallel to the layer or strata of the rock.

Sides are the surfaces which bound the bricks or stones in a direction transverse to the faces and beds.

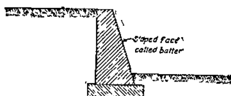
Joints.—The mortar joints between the courses normal to the pressure are called the *bed joints*; the joints transverse both to the beds and faces are termed *side joints* or simply *joints*.

Course—Each horizontal layer or slice of a masonry structure taken between two bed joints is called a *Course*. When the layers are of equal

thickness throughout it is termed *regular coursing;* if the thickness varies, it is termed *random* or *unequal coursing.*

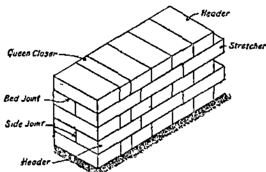
Batter is the slope of the face or the back of a masonry structure.

Fig 1.



Header is a brick or stone which lies with its greatest length perpendicular to the face of the work. *See* Fig. 2.

Fig 2.



Stretcher is a brick or stone which lies with its greatest length parallel to the face of a work. *See* Fig. 2.

Through is a header which reaches from the face to the back of a structure.

Binder is a header which only reaches part of the distance between the face and the back of the wall.

Bond is the name given to the arrangement of bricks or stones in each course, so as to ensure the greatest possible amount of lap, and also to prevent the vertical joints between any two courses making a continuous straight line. *See* Plates 2, 3, and 4.

Closers are pieces of brick which are inserted in alternate courses, in order to prevent two headers from being exactly over the stretchers of the lower course and to obtain a lap. *See* Fig. 2.


King Closer

Queen closers are bricks cut longitudinally in half, or specially moulded bricks of this size. *See* Fig. 2.

King closers are bricks cut like Queen closures on one face, but cut at such an angle as will give the full width of the brick on the other face. *See* Fig. 2.

Breaking joint occurs when the bond is properly carried out, or when *there is no continuous straight line between the joints of any two bricks* or stones either horizontally or vertically.

Bats are small broken pieces of bricks.

Frog is an indentation on the top surface of a brick, made with the object of forming a key for the mortar, and also for reducing the weight.

Footings are the projecting courses which are built at the bottom of a structure, with the object of distributing the pressure over a greater area of foundation.

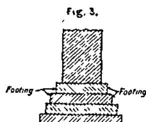


Fig. 3.

Plinth is a projecting base of a wall, and is built to increase the stability, and frequently to improve the appearance of the structure.

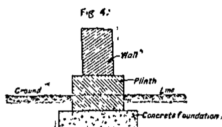
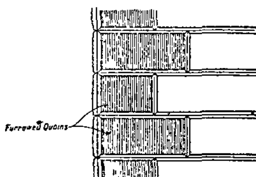


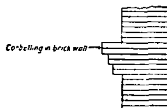
Fig 4.

Quoins are the external corners of building. The term is also applied to the special bricks or stones with which these corners are formed.

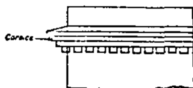
They are of large size, and form the header of one face and the stretcher of the other face.



Corbel is a stone or brick which projects from a wall in order to support some projecting feature, such as a cornice, parapet wall arch, etc.



Cornice is a projecting moulded or ornamental course or courses near the top of a wall.



Coping is the top course of a wall, made of a special shape or form in order to protect the masonry from wet, or other injury, and also to improve the general appearance. In stone-work it is generally made

of ashlar, and the blocks are prepared to cover as large a space as possible.

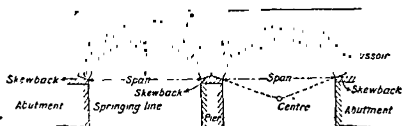


Fig 8

Voussoirs are the blocks of brick or stone which compose the courses of an arch. *See* Fig. 9.

Skewbacks are the upper surfaces of the abutments or piers from which an arch springs, and are so formed as to radiate from the centre of the arch. *See* Fig. 9.

Fig. 9.



Springing line is the intersection of the arch with the body that supports it. *See* Fig. 9.

Key is the central voussoir at the crown or top of an arch. *See* Fig. 9.

Intrados or Soffit is the under or concave side of an arch. *See* Fig. 9.

Extrados or back is the upper or convex side of an arch.

Haunch.—The name given to the lower half of an arch, from the springer midway to the crown. *See* Fig. 9.

Spandrels are spaces directly over the extrados of an arch, and under the horizontal line drawn through the crown. *See* Fig. 9.

Abutments are, in the case of a single arch, the structures which support the arch and from which it springs; and in the case of a series of arches the structures which support only the ends of the series. *See* Fig. 9.

Piers are the intermediate structures between the abutments which support a series of arches. *See* Fig. 9.

tested as above described, doing the same at both ends of the building. This will effectually check the large rectangle. The measurement of other necessary parts of the building, and of cutting lines, etc., should be laid off from this corrected rectangle. Any inaccuracy is thus avoided as it can only occur within these limits, and then must show itself, as the number of rooms and walls must fit exactly. Each corner of cutting line of each room or passage should be marked with a small peg, and its position checked both with regard to its own diagonals, and to the main rectangle.

In laying down this first rectangle, it will be found most convenient to place the pegs at the corners, but as the sides of it represent face lines, and not excavation lines, their prolongations must be marked either with long pegs or pillars, as above described, according to the length of time likely to elapse before the mason requires to refer to them.

The cutting lines may now be scored on the ground, or marked with lines of *surkhi*, and all pegs and strings, not required for future reference, taken up so that the labourers may work unimpeded.

The foundation trenches can now be excavated, but before any concrete is laid the Engineer should always satisfy himself that these have been dug to the full and correct depth.

When the concrete is completed its top surface level must once more be most carefully checked, and on this the lines for the superstructure laid down with absolute accuracy. This is done as already described above by measuring from the guiding pillars.

The lines are usually traced on the concrete surface by stretching strings which have been previously dipped in a mixture of charcoal dust, and water, between measured points; these when pressed on the concrete surface leave a fine black line.

The foundation for the superstructure of the whole building having thus been traced out, the Engineer should satisfy himself that all is correct, for the least mistake here may lead to an error which cannot be rectified later.

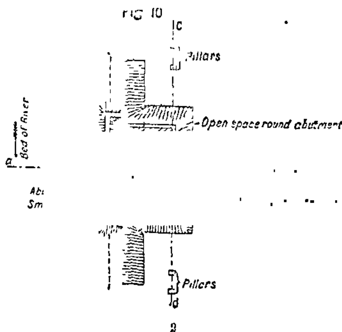
6. Should it be required to lay out a building on very broken or sloping ground the Engineer would use his discretion as to previously levelling the site entirely or partially. Sometimes it would be sufficient—on rocky sloping ground, for instance—to render the slope sufficiently uniform to admit of the hypotenuse corresponding to the several distances marked on plan, and the regular slope of the ground, being laid down; but it would, as a rule, be a quicker plan to level the site, say, down to the level of the top of plinth, or down, say, to that of top of foundations.

Circumstances would, however, fix the point down to which it would be most advisable to cut away the ground.

7. In the case of a bridge the first line to lay down is the centre of the roadway, marking on it the centre of the stream, canal, or railway. All measurements across the stream are taken on this line, and the breadths of the work set out half on each side of it. When this has to be done on level ground it is simple, but to do it at the bottom of a foundation pit blocked up with baulks and shores, and ankle-deep in mud requires both practice and patience. Let us take the case of putting in the abutment of a bridge, any error in the position of which would render the work useless. The leading lines having been laid down on the drawings, the first thing to be done, before breaking ground, is to set out the centre line of the roadway very carefully with a theodolite and ranging rods, for a considerable distance on each side of the work, and to fix its position by erecting the masonry pillars with cuts on them, in some part of the line where there is no chance of their being disturbed. It must always be remembered that this centre line should be most carefully placed with reference to the line of the stream.

Next, the exact position of the abutment on the centre line should be decided upon, and fixed by setting out another line at right angles to the first as c d, which would also be extended beyond the works, and its position fixed by masonry pillars, the exact position of the line on the head of each pillar being marked by a cut.

FIG 10



2

The reduced level of the top of these pillars should be the same, and its relation to the bridge floor should be carefully recorded.

These guiding lines having now been permanently secured, the plan of the abutment may be set out on the ground, the dams constructed, and the earth got out to the required depth. By the time the excavation is ready for commencing the work it generally presents a forest of stays, struts, and shores that would defy any attempt at setting out the work on its own level; it must, therefore, be set out at the level of the top of the dam, and the points transferred or dropped as follows:—

First, the position of the centre line is ascertained by reference to the main pillars, and nails being driven into the timbers at the sides of the dam, a fine line is strained across, the position of the line *cd* is found, and a second line strained across in the same way. In a similar manner other lines are strained from side to side at the required distances, the lengths being measured from the line *cd*, and the widths from *ab*, until the outline of the foundation course is found; the angle points are then transferred to the bottom of the excavation by means of plumb-lines, and the work is commenced, its accuracy both horizontally and vertically being easily tested by measurements from the lines *ab* and *cd* until it is so far advanced as to render this unnecessary.

In very large works such as a big bridge or masonry dam where accuracy is essential, the guiding pillars are built high up either side of the work as described. The distances between pillars may however be very great and therefore intermediate points are given with a theodolite as the work proceeds. Strings can then be stretched between these intermediate points for constructing the work as already described.

8. Preliminary operations.—No attempt should be made to start a masonry work till all the preliminaries have been arranged; and the collection of plant and materials is in full swing. The preliminary *operations for a large work may take many months, but the more thoroughly* they are done the quicker and smoother will be the execution of the actual work.

The Engineer should consider and arrange for the plant, materials, labour, and staff, that he will require at each stage of the work, otherwise there will be most disappointing delays, the contractor's expenses will increase, and he will give trouble when he realises that the work is no longer a paying one. Arrangements should be made for a continuous supply of bricks, stone, *kankar* or lime, sand and fuel as may be necessary.

Roads or lines are required to bring the materials to the sites of the works, and machinery may be required for pumping or for water-supply for grinding lime or mixing mortar, for stone-breaking or haulage purposes. Lime kilns and godowns for storing lime and other materials are generally necessary, and often some accommodation is required for the staff and workmen.

A proper supply of good drinking water is probably the most urgent of all preliminary operations, and it is the one that is most commonly neglected. Local wells are sufficient for small works, but large works require special wells and arrangements for the prevention of pollution; or it may even be found to be necessary to construct a water works system.

CHAPTER II.

PLANT AND SCAFFOLDING.

9. Plant —In England it is customary for contractors to supply all the tools and machinery, the scaffolding and falsework which may be required for the proper execution of the works, and these are included in the contract rates. In India smaller contractors are generally employed, so it is customary to provide all machinery, pumps, tram lines, etc. Scaffolding is generally provided by the contractor, but when there are elaborate centerings for large arches, or falsework for reinforced concrete, it is customary to carry out the work by departmental agency or by a separate contractor.

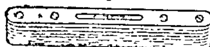
10. Machinery.—For small isolated masonry works no machinery is required. Burnt *kankar* can be ground, and mortar mixed wet with the ordinary mill stone drawn by bullocks. On large works, or when there are a large number of small works near each other, a better outturn both in quality and quantity can be obtained by the use of disintegrators and mortar mills driven by portable engines; and tram lines and trucks should be used for the carriage of bricks, stone, *kankar*, and mortar to the works, or from one part of the work to another.

The ordinary steel tip truck which is used for earthwork (*see* Chapter III of the *Earthwork Manual*) is most useful for the carriage of lime, mortar or ballast from one part of the work to another. For the carriage of stone from the quarries to the works the truck should be removed from the wheel frame, and a base for the stones should be made with thick wooden planks.

11. Instruments used in buildings —The *Level* and the *Theodolite* are required for setting out all large works, and later on for checking and setting out the courses as the work proceeds.

The mason's spirit level is very useful for laying out short horizontal lines, or lines where absolute accuracy is not essential and it is *generally used in conjunction with the straightedge.*

Fig. 1.



A mason's level is also used for checking the accuracy of bed and coping stones, and in other places when a horizontal surface is required.

The Straightedge is a thin strip of wood or steel 2' to 3' long; it is continually used for checking or laying down short straight lines or plain surfaces.

The Square is used for setting out right angles; it is formed of iron, having one arm 12" and the other 24" long. Large sizes of squares are made of thin strips of wood and are useful in laying out right angle.

Fig 12.

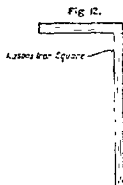
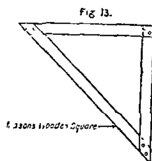
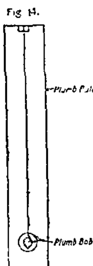


Fig 13.



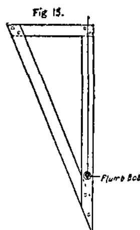
The plumb-rule and plumb-bob are used for setting out or testing vertical lines. The plumb rule consists of a flat, straight-edged thin piece of board, with a line marked on it parallel to one of its edges. When the instrument is vertical the plumb-bob falls directly over this line.

Fig 14.



A *Batter* in a masonry wall is laid out with a bevel plumb-rule (*see* paragraph 32 of the *Earthwork Manual*). The rule consists of three strips of wood which are fastened together in the form of a triangle to make the batter required. One strip is horizontal, the second is vertical with a plumb-bob like a mason's plumb-rule and the third side gives the correct batter.

Fig 15.



When the face of a wall is curved it must be set out by a *face mould.* This is a narrow flat board with one edge cut true to the required curve of the wall, and with a straight line marked on it, which is set truly vertical by a plumb-bob. Large face-moulds are made of several pieces of timber framed together.

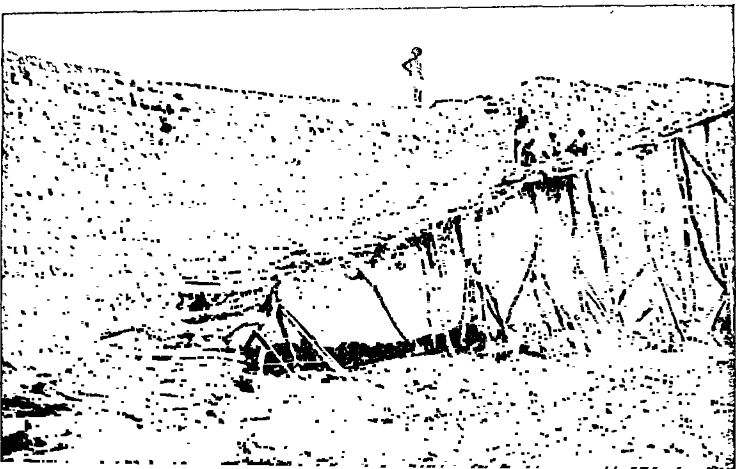
The *trowel* is used for spreading mortar, and in England where it is larger and heavier than the tool used in India, it is also used for breaking bricks or cutting them into a sloped form.

Fig 16.



In India bricks are generally broken and cut to a required shape by a

Plate I.



A "Chali" or "Balli" staging under construction for carriage of materials on to the weir.

light iron tool called *Busuli*, hammer headed on the one side and a chisel on the other side. *See* Fig. 17.


Fig 17.

The tools and machines used for cutting, dressing, and lifting large stones are described in paragraphs 30, 31 and 32, and of Chapter III (Stone Masonry).

12. Scaffolding.—Scaffolds are temporary erections of timber or bamboos which support platforms close to the work, and on these platforms the workmen stand and carry on the construction.

The scaffolding used for brick and for stone masonry is much the same except that for stone walls it is customary to provide two rows of standards, instead of one row, so as to be totally independent of the walls for support to the scaffolding.

In brick-work when a wall has been built as high from the ground level as the bricklayer can conveniently work on it he commences to erect scaffold by fixing a row of poles in the ground.

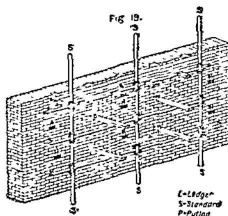


Fig 19.

These poles are called standards, and are placed from 10 feet to 12 feet apart, and about 4½ feet from the wall. Horizontal poles, called ledgers are then fixed to the standards at the level of the work which has been completed. The ledgers are fastened to the standards by nails, bolts, or

rope lashings, and upon these are laid short transverse pieces called *putlogs* which are about 6 feet long and 3 inches thick. The working platform which is made of planks or bamboos is then placed over the putlogs. Header bricks are temporarily omitted, and into these holes one end of the putlog is inserted, while the other end rests on the ledger and is secured by nails or ropes. The putlogs are placed from four to six feet apart, the distance depending on the strength of the platform boards.

As soon as the masons are unable to construct the wall to a further height without difficulty another row of ledgers is fastened to the standards, fresh putlogs are laid, and the platform boards are raised to the new level. The ledgers and putlogs used at the lower stages are left in position to steady the scaffolding, and when the building is a high one or is in an exposed position the scaffolding is stiffened with brace poles placed diagonally across the outside of the standards and ledgers. Care must be taken not to load the scaffold too heavily, lest the putlogs should injure the green masonry upon which they rest. Materials are carried up to the working platform by ladders or by inclined planes, in baskets, buckets (or hods in England) and on coolies' heads. Pulley wheels or windlasses are used when heavy weights have to be raised. A constant and steady supply of bricks or stone and mortar on the part of the labourers (without overloading the scaffolding) should be arranged for. In India the scaffolding is generally made of bamboos, or *sal* or teak poles, and the working platform is generally made with small bamboos instead of planks. Squared timbers fastened by bolts or dog irons are seldom used. For low walls the scaffolding is frequently dispensed with, and a rough working platform is made with the trestles or empty casks, and a bamboo floor laid on top.

13. Scaffolding for stone walls.—The scaffolding for stone masonry is very similar to that described in the previous paragraph for brick masonry. The courses of stone masonry are however not so regular as those for brick-work, and consequently the putlogs cannot conveniently be inserted into the face of the masonry. It is therefore customary to make two rows of standards and ledgers, one inside and one outside the wall, and on these the putlogs are fastened so that the scaffolding is entirely independent of the building.

On large stone masonry dams the wall itself is used as the working platform, and stones and other materials are carried up on an easy incline made with poles and bamboos and old cement casks. For the

top portion materials are also sometimes carried to the site in tip trucks which run on lines laid on top of the wall. This is however a slow method, and only permits of work being carried on at the two termini of the lines.

Gantries, cranes, windlasses, etc., are seldom used in India for lifting large stones and other weights up to the work, but when used the scaffolding must be made much stronger than it is customary to make it.

A common method for raising heavy weights, such as rolled beams for roofs is to haul them up an inclined plane made of *sal* or teak poles, or rails.

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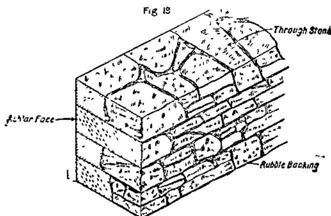
CHAPTER III.

STONE MASONRY.

14. **Classification**.—There are two main classes of stone masonry which are known as "Ashlar" and "rubble," and between these two classes there are many gradations. The classification is based on the size and shape of the stones and on the manner in which the joints (whether bed or side joints) are formed and executed.

Ashlar is stronger than brickwork, but is more expensive because each stone has to be carefully dressed.

Rubble is generally cheaper than brickwork, when the stone quarry and the brickfield are about the same distance and close to the work, and, if well done, is more durable. Bricks are however of uniform size and can therefore be laid according to a recognised system; stones vary greatly in size and shape, and considerable skill and judgment is required to secure a satisfactory bond.



Different kinds of masonry are frequently combined. For instance, walls may be built with an ashlar face and rubble backing (*see* Fig. 19), or with a stone face and brick backing. Again, in weirs and in thick walls coursed rubble facing, see para. 23, is combined with plum concrete filling.

15. **General principles and precautions.**—The general principles to be observed in the construction of all classes of stone masonry are quoted below from para. 240 of Rankine's *Civil Engineering*. These principles are the essence of good work and should be carefully noticed. Most of them are equally applicable to brickwork.

(i) "Build the masonry, as far as possible, in a series of courses, perpendicular, or as nearly perpendicular as possible, to the direction of the pressure which they have to bear, and avoid all long continuous joints parallel to that pressure by *breaking joint*."

(ii) "Use the largest stones for the foundation course."

(iii) "Lay all stones which consist of layers or *beds* in such a manner that the principal pressure which they have to bear shall act in a direction perpendicular, or as nearly perpendicular as possible, to the direction of the layers. This is called *laying the stone on its natural bed*, and is of primary importance to strength and durability."

(iv) "Moisten the surface of dry and porous stones before bedding them, in order that the mortar may not be dried too fast, and reduced to powder by the stone absorbing its moisture."

(v) "Fill every part of every joint, and all spaces between the stones, with mortar, taking care at the same time that such spaces shall be as small as possible."

Unless the Engineer is most particular he will find that masons will try to scamp every one of the items mentioned and especially numbers (*iii*) and (*v*).

In addition to these general principles there are many other precautions which it is necessary to take to ensure the execution of good masonry work of all descriptions, both in stone and brick. A few instances will be useful to the student, and will help him to learn the full details after a little practical experience.

Top surface rock which is weathering, or soft rock should never be used in any important work.

In Europe the atmosphere is generally so damp that it is seldom necessary to keep the completed work wetted by artificial means. In India, however, it is so dry that all the work must be kept damp during the construction and on completion Both masonry, plaster, and pointing should be watered for at least a fortnight. If this is not attended to the mortar will not set, and will be of very little more use than mud. It is essential, but often most difficult, to ensure the mortar being good. The *kankar* may not be properly cleaned or broken, white lime may be insufficiently slacked, under or over-burnt. Bad *kankar* may be mixed up and ground with some that is good ; the wet grinding of mortar may be shirked, an excess of sand or the wrong proportion of *surkhi* may be mixed with the lime.

The contractor will always try to use up any lime which has been damaged by rain unless this is removed from the site and measured up, so that it cannot be brought into use again. If the masonry contractor also supplies the materials, he may endeavour to use such as are of an inferior quality. Should any inferior material be found at the site of the work it should at once be removed at the contractor's expense, for, if left near the work, it will certainly be used when no one is looking.

In brickwork and concrete with brick ballast the materials may be insufficiently soaked with water before use ; in pointing the joints are sometimes not properly cleaned out, and the surface may be insufficiently wetted before the pointing is made ; in plastering the work is liable to be rushed and insufficiently beaten, and is often allowed to dry too quickly.

16. **Method of Building.**—The usual method of building a masonry wall to the correct dimensions of the drawings, is to set two face stones accurately to the required dimensions of the wall, at some distance apart in the same course. These stones are set truly level, as well as plumb with the face of the wall. The end of a fine string is then wound once or twice round a loose stone, and this is adjusted on one of the fixed stones, and the string is stretched to the other, and then also wound round a loose stone, so that it can be stretched and adjusted just to mark the top outer edge of the course about to be laid. The face stones of this course are then laid to touch it, and when the same thing has been done on the other side or face, the centre is filled in and the course completed.

To lay each stone the mason spreads the mortar carefully on its bed a little thicker than he requires it to be, and also plasters it against the end of the stone last placed. He then places the fresh stone carefully, and by pressure or smart blows with his trowel or hammer, beds it firmly in the mortar in its proper position, and strikes off any mortar that has been squeezed out of the joint in front with his trowel. When a course is completed, the guide string will be laid for the next, in a manner similar to the method already described. Throughout the work the face must be constantly tested with the plumb-rule.

17. **Ashlar Masonry** consists of carefully-dressed blocks of stone, cut in regular figures, generally rectangular, and laid in courses of uniform depth which are seldom less than one foot. Ashlar masonry is used in India for cut waters of piers, springing and keystones of brick arches, arches, beds for steel girders, copings for inferior types of

masonry, top of crest walls of falls and dams, floors of falls, etc., and in buildings for ornamental and face work, also for quoins, cornices, etc.

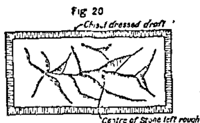
Ashlar is by far the most expensive type of masonry, it depends for its strength mainly upon the size of the stones, the accuracy of the dressing, and perfection of the bond and but slightly upon the quality of the mortar.

In England the joints seldom exceed $\frac{1}{8}''$ in thickness, but in India this fine dressing is seldom possible, and considerably thicker joints are preferable. It is impossible to fill very fine joints with mortar and a moderate amount of roughness adds to the stability by a better adhesion of the mortar, and thereby a greater resistance to sliding. The size of the stones used in ashlar masonry varies with the kind of stone, the nature of the quarry, and the appliances which are available for lifting and moving the stones. From some quarries (such as many of the sandstone quarries near Agra, Dholepur, and Mirzapur) practically any size of stone can be obtained. The weight of these stones varies from 140 to 160 lbs. per cubic foot, the size of the block that can be used is therefore frequently limited by the power of the lifting appliances which are available.

"In order that the stones may not be liable to be broken across, no stone of a soft material (such as the weaker kind of sandstone, and granular limestone) should have a length greater than three times its depth. In harder materials, the length may be four or five times the depth. The breadth in soft material may range from one and half times to double the depth, in hard materials it may be three times the depth."*

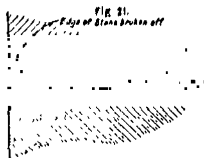
18. The faces of ashlar stones are sometimes dressed smooth, and sometimes left rough, but in the latter case a carefully chiselled border or "draft" is cut round the four edges of the face, forming sharp and straight edges with the chisel draft of the beds and joints, to enable the stone to be accurately laid, and also to improve the appearance of the work.

Fig 20

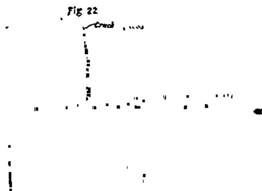


* Rankine's Civil Engineering.

The bed and side joints are accurately dressed to plain surfaces, but care must be taken that bed joints are not dressed hollow, this may sometimes be done to show a fine joint on the face without the trouble of carefully dressing the whole bed. The entire weight of the superstructure is then thrown on the front edge, and small pieces are liable to be splintered off (*see* figure 21); the stone is then said to be "flushed," at this point.



Again, when a stone is being dressed, the back of the joint is frequently left hollow in order to save trouble. To give the block of stone its proper set it has to be under-pinned by small pieces of stone, *see* figure 22. The stone is then only supported at the front and at the back, and is liable to crack in the centre from the weight of the superstructure, *see* figure 22. This is necessary in rubble work but must never be allowed in ashlar masonry.



Every stone should be fitted dry into its proper place and all irregularities rectified before it is finally laid in mortar.

19. Bond between two types of masonry.—When the face of a w consists of cut stone and the filling or backing of rubble, plum con or other kinds of masonry, it is most necessary to make a ood bo connection between the two types.

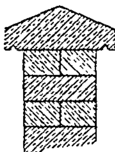


Fig. 23.
ILAR WALL & COPING.



PING

Fig. 25.
COURSED RUBBLE WALL.

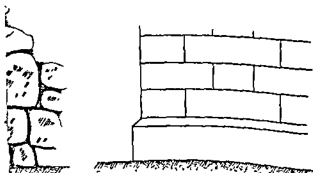


Fig. 27.
ASHLAR WALLING

Photo. Zinco April, 1933 —No.8593 2000

The cut stone should be dressed and bedded fair for a certain distance, say one foot from the face, but every third or fourth stone should run in much deeper than this, so as to lock into the backing, and these projections may be thinned off or altered to suit the filling or backing; but wherever it is possible they should be left larger than the dressed portion, and the backing or filling built round them, so as to form a firm connection.

20. Bond.—Various methods are used by builders for the bond of cut stone, but the strongest system consists of alternate header and stretcher stones in each course, similar to Flemish Bond in brick-work (*see* paragraph 39).

In no case should the ends of the headers form less than one-fourth of the whole area of the face of the work.

On the face of a work the vertical joints of a course must never lie directly above the vertical joints of the course below; all stones must overlap or break joint and, as far as possible, the vertical joints of one course should lie over the middle of the blocks of the course below, or at least from 4" to 6" on one side or the other of the vertical joints of that course.

The bond across the thickness of a wall is of the greater importance, in some cases "through bonds" extend from the face to the back of a wall at regular intervals, in other cases headers start alternately from opposite sides of the wall, and in the case of thin walls cover about two-third of the thickness, while in thick walls they merely tie well into the filling.

"Through" for anything but very thin walls are not recommended, because the beds are seldom true, and then the pressure of the superstructure comes on a few points and thus the stone is liable to crack. Through bonds should not be placed directly over one another; the bond stone of one course should lie over the centre of the distance between the two bonds in the course below. It is a good practice to lay all the bonds of a course in position before the remainder of the course is built; these stones are generally from 4' to 5' apart.

21. Block in course resembles ashlar in that it consists of rectangular blocks of stone, which are dressed on all sides. The dressing is, however, rougher than in ashlar, and is done with a hammer; the courses are also smaller than those used in ashlar, the depth varying from 6" to 9". The term "block in course" is seldom used in India; it would probably be called ashlar or rough ashlar. The same rules as have been given for ashlar for bond and proportion of stones, hold when applied to this class of masonry.

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22. **Rubble masonry.**—There are many kinds of rubble work, such as "coursed rubble," "uncoursed rubble" or "random rubble" masonry, "Kentish rag," etc, the different names depending on the arrangement of the stones, or on the work required to be done upon them; but the only two varieties which need be mentioned here are coursed and uncoursed rubble masonry.

In all kind of rubble work the stones are merely roughly dressed with large hammers, so that the strength of the work depends greatly on the excellence of the mortar, the bond, and the skill and care with which the irregularly-sized stones are fitted together.

Headers and through bond stones must be regularly provided, the remarks made in paragraphs 16 and 19 regarding the number, the size, and the position of these stones in ashlar masonry apply to all kinds of rubble work.

It is most important that all stones should be placed on their natural beds, and be as nearly horizontal as is possible. The hearting must be filled with good stones, and chips or spalls used to fill the spaces between the stones. A mason, if left to himself, will invariably place all face stones similarly to bricks-on-edge, and will fill up the hearting with any sort of rubbish, and will frequently leave large empty spaces.

23. **Coursed rubble** consists of a series of horizontal courses varying from 6" to 18" in thickness, each of which is correctly levelled before another course is built upon it. The side joints are not necessarily vertical, the thickness of the courses varies, but the thickest courses should always be placed at the bottom and the thinner courses higher up in the work. Each course is usually the thickness of the stone, but occasionally the whole or portions of a course is made with a depth of two or more stones. All headers must, however, be of one-stone thickness. Coursed rubble is commonly used in India for all kinds of large and important engineering works. If the materials are good and the work carefully carried out, it is suitable for every kind of work except cornices, copings, arches and ornamental work.

24. **Uncoursed rubble** is not built in courses, but otherwise it is very similar to coursed rubble masonry. The stones are of more irregular size and shape, but the rules regarding bonds and headers are applicable to both types. The cost is practically the same as for coursed rubble, and as it is weaker and more difficult to construct really well, it should never be used in engineering works of any importance. The resistance to crushing is little more than that of the mortar which it contains. The angles or quoins should be constructed with cut or hammer-dressed stones.

25. Dry stone masonry is built in a similar manner to coursed rubble masonry, with the exception that mortar is omitted from it. It is used for fence walls, for retaining walls in cuttings, for walls at the toes of high embankments and also as pitching in channels to prevent scour. In such walls a coping of stones on edge with mortar is generally added to preserve the wall from being knocked about. In retaining walls a top coping is often added with stones laid on edge, and without mortar. (Also *see* paragraph 111.)

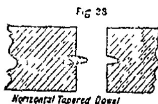
26. Method of strengthening joints.—The adhesion of the mortar and the weight of the superstructure are sometimes insufficient to keep stones from movement; so metal or hard stone connections of various forms are used to increase the stability of the structure.

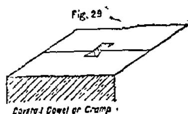
Cases in which these methods are applicable are in light-houses and sea walls in exposed positions, in coping stones or inclined walls, in the tops of weirs and floors of falls, and in detached stones which are not kept in place by the surrounding masonry, or indeed in any position where lateral movement of the stones is likely to occur by their own weight or by shocks caused by wind, water or machinery. The best metal to use is copper or bronze as neither of these rusts, but the cost makes the use of these metals prohibitive in India. When iron is used it must be thoroughly protected from the air and moisture, or it will rust, increase in bulk and split the stones.

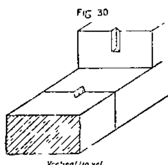
Cast-iron is less liable to rust than wrought-iron.

Painting or galvanising is sometimes done for protection, but the best method for preventing rust is to cover the metal with Portland cement, or several coats of cement wash.

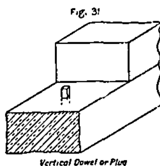
27. Dowels are pins about 1" thick and 3" to 5" long which fit into the holes made in two adjacent blocks of stone. These pins are made of hard stone, slate, or metal and of any shape found to be convenient. Dowels are placed vertically and horizontally to assist in the connection of the joint; they are also used in the centre of a stone to prevent sliding, *see* figures 28, 29, 30, and 31.


Fig 28
Horizontal Tapered Dowel


Fig. 29
Central Dowel or Cramp

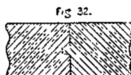

Fig 30

Vertical Dowel


Fig. 31

Vertical Dowel or Plug

28. Joggles —Stones are said to be *joggled* together when a projection is cut out on one stone and fits into a hole or groove which has been made to correspond in the other stone. This entails great labour, and waste of stone and consequently is seldom done. A more economical joint is made by cutting grooves in both the stones, and then inserting a hard stone or metal tongue.


Fig 32.

29. Metal cramps are used as fastenings on the top of copings and in similar situations, but they should be used as little as possible as they are liable, by rusting and expansion, to injure the stones in which they are placed. *See* paragraph 26.

Cramps are made from thin pieces of metal of varying length and sectional area according to the requirements of the work, and both ends of the cramp are roughened and bent at right angles for a distance of about 1½" and fixed in grooves cut in the stones, *see* figure 33. The cramp must be thoroughly embedded in lead, asphalte, or cement mortar, but the last is recommended.

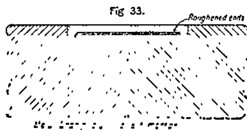


Fig 33.

30. **Dressing of stones.**—For blasting purposes holes are sunk into the solid rock with jumpers and sledge hammers, and for ordinary rubble work the stone thus removed is roughly dressed into suitable shapes by heavy hammers. There is great skill required in dressing the stones. A good mason dresser will examine the irregular block as it comes from the quarry, and, with a few blows of a heavy hammer of a special shape will quickly knock off pieces here and there, and form a roughly-squared block, which is suitable for coursed rubble masonry.

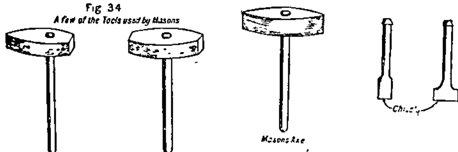
Sandstones are generally quarried without blasting, the blocks being removed by hammers and wedges.

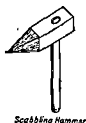
For fine dressing, mallets, hammers, chisels, saws and mason's axes are used.

The usual method of dressing a surface for ashlar work is to cut narrow channels or drafts around and across the stone with a chisel and mallet, to the depth of the fair surface required. and then to use the chisel, axe or hammer to work down the intermediate portions into the same surface as the drafts.

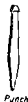
Finely-grained stones are sometimes brought to a smooth face, and then rubbed with a small piece of stone and sand to produce a perfectly even surface. The harder and more coarsely-grained stones are generally *tooled*, that is, the marks of the chisel are left on the face. When the stones project beyond the joints the work is said to be *rusticated*. In massive erections, when the stones are large, and a bold effect is required, the fronts of the blocks are left rough, as when they come out of the quarry, and are called *quarry-faced*. In all ashlar work, even when quarry-faced stones are used, there must be a chisel draft round the edge of the face, in order that the stone may be accurately set. Polishing of marbles and granites is seldom required in engineering works, but when it is done machinery is generally used. The method of procedure is to rub the block with revolving pads on which iron, sand, and water are used, and then with softer pads on which there is emery powder, and finally with soft pads covered with putty powder.

Fig 34
A few of the Tools used by Masons

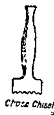


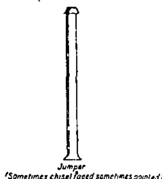

Scabbling Hammer


Wood Mallet


Punch


Point


Chase Chisel

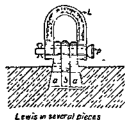

Jumper
(Sometimes chisel faced sometimes pointed)


Iron Hammer

31. Methods of securing stones to be lifted.—Rough and hard stones are generally lifted by chains which are passed round them, but when softer or finely-dressed stone is hoisted, or when it is necessary to lower the block accurately into its final position, a special tackle (such as a Lewis or Nipper) is required. There are several kinds of Lewis as shown in figures 35, 36, 37, 38 & 39.

Lewis in separate pieces—A hole taping upwards, about 3' deep is cut in the upper surface of the stone that has to be raised, *see* figure 35, the two tapering side pieces *a*, *a*, of the Lewis are inserted first, and placed against the side of the hole, the centre-piece *b* is then inserted, and secured in its place by a pin *p* passing through all three pieces, and also through the ends of the ring L, into which the hook of the chain is inserted when the stone is raised. When the stone is being raised, the Lewis on account of the wedge shape of the side pieces, becomes tightly jammed and cannot be pulled out.

Fig 35



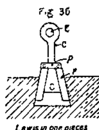
Lewis in several pieces

Lewis in one piece.—This is an improvement on the ordinary Lewis mentioned above as all the pieces are connected and thus much time is saved in fitting the tackle.

The chain is fastened to a ring which passes through the eye *(e)* of the centre-piece (*C*), of which the lower part is wedge-shaped.

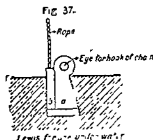
The side-pieces (*F*) are connected by and hinged to cross-pieces (*p*) of flat iron on each side of the centre bar. When the stone is being lifted the centre-piece of the Lewis is pulled up, the wedge at the bottom forces the side-pieces out upon the sides of the hole, and the greater the pull the tighter becomes the grip of the Lewis.

To remove the Lewis a blow of the hammer must be given on the head of the centre-piece, which is then driven downwards and thus the side-pieces are loosened and the Lewis can be removed.



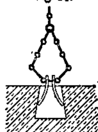
Lewis in one pieces

Lewis for use under water.—Stones can be lowered and set under water without difficulty by means of a Lewis shown in figure 37. The wedge-shaped piece (*a*) is first inserted in the hole, and then the rectangular block (*b*) to which a rope is attached. This block is pulled out by a rope whenever it is required to remove the Lewis.



Other types of Lewis are shown in figures 38 and 39.

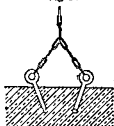
Fig 38.



Another type of lewis sometimes used

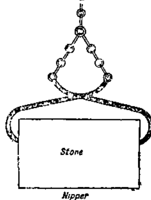
In the type shown in figure 39, two pins are let into holes which slope towards each other. The pins fit the holes closely. When a strain is applied to the lifting chains these pieces jam in their places and support the weight of the stone.

Fig 39



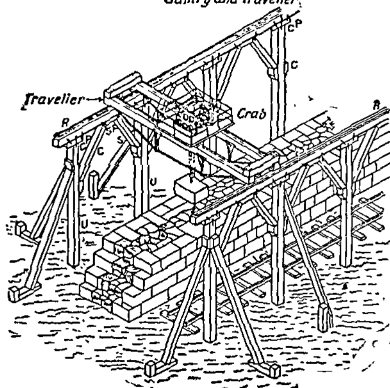
Nippers.—A small cut is made on both sides of the stone to be lifted so as to give the points of the nipper a hold. The upper ends of the nipper are attached by short chains to a central ring which is fixed at the end of the hoisting chain. The action is clear, but to avoid accidents care must be taken that the claws of the nipper are placed above the centre of gravity of the stone, and also at a sufficient distance below the top to avoid the risk of the edges being broken off.

Fig 40



Nipper

32. **Machinery for lifting stones.**—The ordinary scaffolding described in paragraph 13 is not strong enough to carry the machinery which is used for the lifting of heavy blocks of stone. In such cases a gantry is erected with squared timbers, *see* figure 41.



The uprights are placed from 10′ to 20′ apart according to the size of the timber which is available, and the work required. On top of these uprights are fixed horizontal beams called runners, these are also supported by struts marked S, S, which butt against straining pieces S P and rest on cleats C.

The uprights should be strutted at the ends and on the outside as shown in figure 41.

The timbers are generally joined by dog spikes and not bolts as the latter are apt to injure the timbers.

The traveller consists of two trussed beams about 4′ or 5′ apart and connected at the ends by a carriage with a pair of wheels. On top of the beams are fixed rails and on these a travelling crab is placed.

The materials to be lifted should be brought from the quarries in trucks, and run under the traveller. The traveller can move from end to end of the grantry, and the crab can be moved across from side to side and thus a stone can be lifted and placed in any required position. A very useful type of gantry is shown in figure 42.

This runs on rails and can be moved from place to place wherever it may be required.

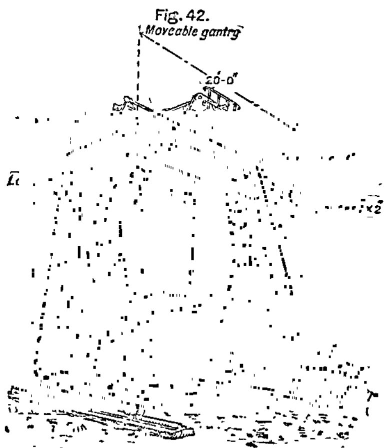
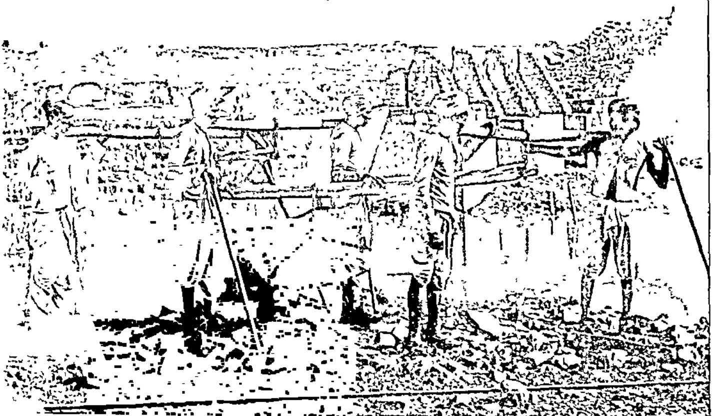
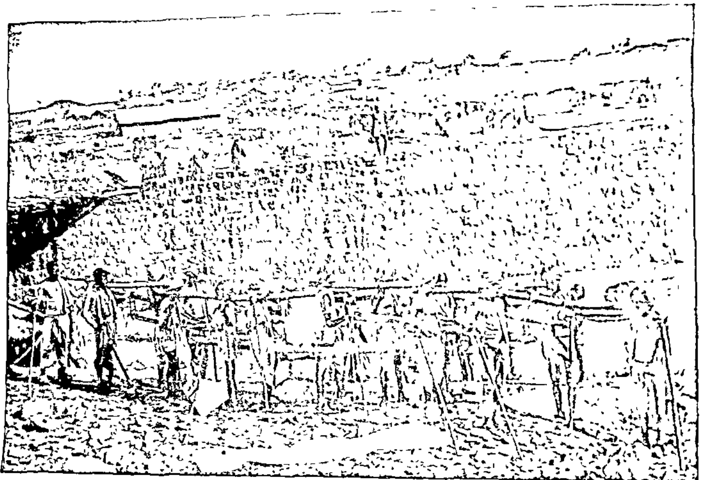


Fig. 42.
Moveable gantry

Plate II.



Chhawala or method of carrying a stone by six men.



Solawala or method of carrying a stone by 16 men.

A common type of Derrick crane worked by hand is shown in figure 13. It is very useful for lifting stones from the quarry to the trucks or carts.

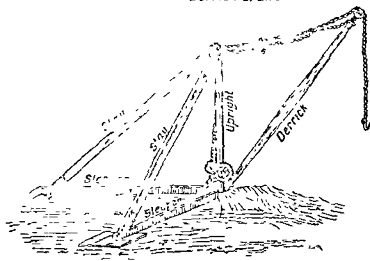


Fig. 43.
Derrick crane

Machinery is being more and more used every year in India, but still it is only on the very large and important works that any is used for lifting heavy stones. There is always the difficulty regarding the timbering for the special scaffolding or gantries, the difficulty of moving the machinery from place to place. It is generally cheaper to use poles, chains, and special weight-carriers as is described below. A chain is passed round the stone to be lifted or carried, and fastened to a stout pole, two, four, six, eight, sixteen or any number of men, according to the weight to be carried, then lift and remove the stone to the required site.

If only two men are required, one will remain at either end of the central pole, and rest it on their shoulders.

When four men are required, a cross pole is attached to each end of the central pole and the ends of these cross poles rest on the men's shoulders.

When eight men are required, other cross poles are attached to the ends of the previously-described cross poles, and in the same manner the ends of those cross poles rest on men's shoulders. Similarly, the number of poles and the men to bear them can be increased to any number that may be necessary to lift the stone.

Actual photographs of 6 and 16 men raising large stones and carrying them to the work are given in photos. I and II. The men always carry stout sticks in the form of a crutch to steady themselves.

Sometimes heavy weights weighing several tons (such as sluice gates in a weir) are lifted up and placed in position by means of ropes, poles and pulley blocks. One or more tripods can easily be made with stout poles and to these suitable pulley blocks may be attached and very heavy weights can then be raised. Another simple expedient for lifting heavy weights is to fix a stout pole on a firm base, guy it up carefully with ropes, and at the top end of the pole attach a suitable pulley block. The pole resembles the jib of a crane, and one or more of these poles will enable large weights to be lifted without trouble.

CHAPTER IV.

BRICK MASONRY.

33. A full description is given in Building Materials of the manufacture of the various kinds of bricks. It will therefore be sufficient to state here that in all purely engineering works nothing but first class bricks, namely, sound, fully-burnt, and properly-shaped bricks should be used. Badly burnt or shaped bricks can however be used for temporary structures and unimportant buildings. When good bricks and mortar are used, and proper bonding is done, brick masonry is quite as durable and strong as coursed rubble stonework, though it does not compare with special stone work such as ashlar, or block-in-course masonry.

When there are stone quarries near the site of a work, rubble masonry is generally cheaper than brick masonry, but elsewhere brickwork is much the cheaper.

For thin walls such as in dwelling-houses, it is advisable to use brickwork instead of stone masonry unless stone is much the cheaper.

For archwork bricks should always be used, if possible, as a good arch cannot be built of stone except at great expense in dressing the blocks.

Bricks of different sizes and shapes should never be allowed in a work except for special purposes, and then the correct shape or size should be especially moulded and burnt to suit the work. For circular piers, cornices, coping, and such like works specially burnt bricks are most useful and much time is saved in the dressing. They also give a better weathering surface to the brick. If the bricks are not burnt to the shape required, care must be taken to prevent the bricklayers from selecting and cutting the softest bricks they can lay their hands on.

34. General principles and precautions.—The general principle and precautions to be observed in the construction of all classes of stone masonry are described in paragraph 15, and most of them apply equally to brickwork. But as they cannot be too carefully remembered, those that refer to brickwork are repeated below, and other points which are specially applicable to brickwork are added.

(1) Only such bricks should be used as are properly burnt, and properly shaped "Bats" must be used when it is necessary to make a closure,—that is, to finish the end or a corner of a wall, or side of an opening, and even then no piece smaller than half a brick should be used.

(2) The beds of the courses must be perpendicular, or as nearly perpendicular as possible, to the direction of the pressure which they have to bear; and the bricks in each course must break joint with those of the courses above and below it, by overlapping to the extent of from one-quarter to one-half of the length of a brick.

(3) The surfaces of all bricks must be cleaned and then soaked thoroughly in water before they are laid, in order that they may not absorb the moisture of the mortar too rapidly. All completed work should be kept thoroughly damp for a fortnight after it has been built.

(4) Every joint must be thoroughly filled with mortar, care being taken that the thickness of mortar does not exceed about a quarter of an inch, also that the height of four completed courses measures one foot.

(5) The thickness of walls should be made an even multiple of half a brick. In India it is customary to burn bricks to measure 10" × 5" × 3" including the mortar joint, the thickness of all walls should therefore be some multiple of 5".

(6) Unless brick-on-edge is specified, all bricks should be laid on their proper beds with the "frog" on the upper side. Bricklayers in India will prefer placing the frog at the bottom of a course as this enables them to use less mortar.

(7) Mortar must be ground wet before it is used. Reject over-burnt and under-burnt *kankar*, and imperfectly slacked white lime. Only use clean sharp sand, and *surkhi* that has a distinct reddish tinge. Be most careful that the mixture used for the mortar is according to the specifications. Reject mortar that has been left standing and has commenced to set.

35. **Settlement.**—All possible precautions must be taken to diminish, as far as practicable, the danger of unequal settlement of the earth both in the foundations and in the wall itself. When the ground is treacherous, it is advisable to give deep foundations so that the work be built on earth that is not affected by atmospheric conditions; and it is also advisable to reduce the intensity of pressure (by stepping out the foundations) to a low limit as well as to equalise this pressure at all points.

Walls that are heavily weighted must be built up uniformly, and great attention must be paid to the bond and the correct fitting of the courses. The materials used should be uniform in quality and size, and the mortar joints should be kept as fine and as uniform as possible. In India it is

particularly difficult to follow these directions, as the size and quality of bricks are seldom uniform, it is difficult to grind the mortar finely enough, and if the Engineer insists upon fine joints, he is likely to find that the mortar filling has been scamped.

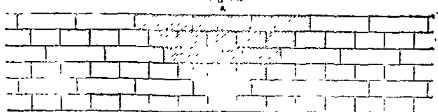
36. Bond —A good bond is just as necessary in brickwork as in stone masonry, and the various forms adopted are only fixed types which have been decided upon, so as to avoid delay among the masons, who would otherwise lose time in thinking out how to lay each brick. These fixed types also allow of any number of men to work on a wall at the same time and ensure their work fitting together accurately. The art of bonding consists in laying each brick so that it shall close up as many joints as possible (both sideways in its own course, and also downwards in the course below), and in avoiding continuous joints. Bonding of one wall to another is equally necessary, and when a brick wall is being built, which is likely to be extended at a future date, it is customary to tooth it, by which is meant that each header course should project a quarter of a brick beyond the stretching courses above and below to enable the new work to be bonded to the old.

When, however, there is a likelihood of unequal settlement between the new and old work, or between two adjacent parts of a new work (due to unequal heights or unequal weighting), it is advisable to have no bonds between the parts. Each portion should be built independently, and when settlement has taken place the joint should be closed by pointing.

37 In effecting repairs of masonry, when new work is to be connected with old, or when a continuous wall is built up in portions, the ends of each portion should be *racked back*, or built in steps, and the wedge-shaped piece A (*see* fig 44) should form the junction between the two. This must not be built till both portions are thoroughly set lest there should be a crack at the junction.

Whenever new work is joined to old, the old work should be thoroughly scraped, cleaned and wetted.

Fig 44.



38. **English bond.**—There are many kinds of bonds used in brick masonry, but the two commonest are English and Flemish, and of these the English is the stronger and should be used in all engineering works. In thin walls of $1\frac{1}{2}$ bricks or less there is very little difference in the strength of the work done with either bond.

In plate 2 are given plans and sections of walls from 1 to $3\frac{1}{2}$ bricks thick, showing the junction of two walls at right angles with one of the two walls ended and cut of square.

In building this bond the following points should be remembered :—

(*a*) The courses are alternately headers and stretchers.

(*b*) The closer brick should always be next to the quoin or corner header.

(*c*) In walls the thickness of which is an even multiple of a whole brick, the same course will show either headers or stretchers in both the front and back elevations, but in walls when the thickness is an uneven number of half bricks, a course that shows stretchers on the face will show headers at the back or *vice versâ*.

(*d*) Bricks do not break joint with each other in the same course. The joints across the thickness of a wall are straight and consequently it is very necessary to flush the joint fully. Some object to this bond because, if it is not correctly flushed, rain may come through the wall, but any attempt to break these transverse joints is a source of weakness and is therefore not to be recommended.

(*e*) There are twice as many vertical joints in a heading course as there are in a stretcher course, therefore the vertical joints between the headers must be made thinner than those between the stretchers, otherwise the lap obtained by means of the closer would soon disappear.

(*f*) Bricks are laid as stretchers only on the faces of courses, the fillings of all courses are entirely headers.

(*g*) A returned end of a wall has a bond similar to that on the face of the wall.

(*h*) In detached walls when the length of the face is an uneven number of half bricks, a bat will be required in the stretcher course of the face ; when the length is an even number of bricks a bat will be required in the stretcher course of the back of the wall.

The student is recommended to draw out the plans of the courses for the different thickness of wall, and if he remembers the rules mentioned above he will realise how easy the bond is to build.

In plates II, III and IV the closer bricks are marked in red to enable them to be easily distinguished. In plate II for the English bond the closers for the right angle junction of two walls are shown diagonally. The first closer must be next to the corner header, but the closers for the filling and inner portions of the junction might be made similar to those shown in plate IV, namely, near the outer face of the wall. Both methods are sound, but most Engineers prefer that shown in plate II.

In walls of greater thickness than 1½ bricks there is a deficiency of stretchers in the centre of the wall. This is sometimes remedied by introducing courses of bricks placed diagonally (*see* plate V).

39. **Flemish Bond.**—There are two varieties of Flemish Bond, called Single or Double Flemish Bond. In both varieties the elevation of the face is the same, every course consists of alternate headers and stretchers, and every header is immediately over the centre of a stretcher in the course below it; closers are placed in alternate courses next to the corner header to give the lap. The elevation of the back is the same as the front for Double Flemish Bond (*see* plate IV).

In Single Flemish Bond (*see* plate III) the filling and backing consists of English Bond. This bond is used when expensive or special bricks are required for the face of the wall; it is also recommended by some people in the belief that some of the defects of Double Flemish Bond in the interior of the wall are thus obviated.

Flemish Bond is weaker than English Bond because a larger number of bats and stretchers are used, but the appearance of the face is considered to be superior. It is certainly more economical as a large number of broken bricks can be used up. The sections given in plate III show that in certain parts of the wall straight joints occur throughout the whole depth. The plans of the courses show that in all wall consisting in thickness of an odd number of bricks, a large number of half bricks have to be used in the centre of the wall. In addition to these defects in the bond it will be found in practice that many masons only pay attention to the bond of the face, the filling and backing being done anyhow. Again, they are apt to make false headers, which are half bricks and do not bond with the interior of the wall. In the plans of the courses

2, 4, 6, etc., in plate III the headers are shown as false headers which are usually adopted, but they can be altered into true headers.

It will be seen from the above remarks that there are many objections to Flemish Bond. By its use it is harder to keep a wall to the correct bond than by the employment of English Bond, and it should never be adopted for important Engineering structures, but for dwelling houses and works of that nature it may be used without causing anxiety.

40. There are many other varieties of bond which are known as Dutch Bond, Stretching Bond, Heading Bond, Garden or Boundary Wall Bond, Facing Bond, Raking Bond, Diagonal Bond, Herring-bone Bond, etc. These are seldom used in Engineering works with the exception of the Diagonal Bond.

Dutch Bond consists of alternate header and stretcher courses, but in every alternate stretcher course a header is introduced as the second brick from the quoin; three-quarter bricks are used in all the stretcher courses at the quoins, and closers are omitted in the header courses.

Stretching Bond is used for half brick walls such as partition walls. All bricks are laid as stretchers on the face.

Heading Bond.—All bricks are placed as headers on the face. This brick bond is used for foundation footings, corbels, cornices and curves.

Garden or Boundary Wall Bond.—This bond is used for walls one brick thick and consists of stretcher courses with a header inserted after every third stretcher.

Facing Bond consists of three courses of stretchers to one of headers; closers are only used in the header courses.

Raking Bond.—There are two varieties of Raking Bonds, namely, Diagonal and Herring-bone Bond (*see* plate V). Raking courses are sometimes used in thick English Bond walls in every 4th to 8th course, with the object of increasing the strength in a longitudinal direction, and thereby remedying the want of stretchers. Raking Bonds are placed in the stretcher courses in walls of an even number of half brick in thickness. Alternate courses rake in opposite directions.

Diagonal Bond is used in walls from 2 to 4 bricks in thickness. Care must be taken that the triangular spaces at the back of the facing bricks are filled in with properly cut pieces. The bricks are laid diagonally, at such an angle with the face that they will just fit in without being cut.

Herring bone Bond is used in walls of more than 4 bricks in thickness; it is also used to form ornamental panels in walls and in floors. This is a bad bond for anything except ornamental purposes. The triangular spaces at the back of the facing bricks and the central squares must be carefully filled with cut bricks. The bricks are laid at an angle of 45° commencing at the centre of the wall and running towards the front and back faces.

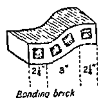
41. Hollow walls are frequently built in England to obtain a drier interior than would be possible with solid walls The cavity between the two walls prevents the conduction of dampness, and also makes the inside temperature of the walls more equable.

An outer half brick wall is built and connected with the inner wall by small pieces of hard stone, brick, brick or iron ties. The space between the two walls varies from 2″ to 3″, and this space must be carefully ventilated with inlets and outlets at the top and bottom of the wall. Gratings with small perforations are fixed at the opening to prevent rats and other vermin from entering. No economy is effected by the use of this type of wall.

In stone walls a thin brick wall is made on the inside and the thicker wall on the outside, but when both inner and outer walls are of brick, the outer wall should be the thinner one. The roof is arranged so as to rest upon the thicker wall.

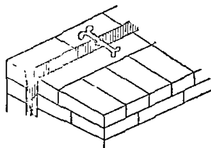
Figure 51 shows a few of the ties which are used, but whether specially moulded bricks or iron ties are used, a slope or hollow should

Fig 51



Bonding brick

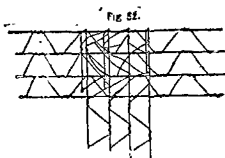

Iron tie


Hollow wall with iron tie

be given so that water is not run into the inner wall. Ties are placed about 3′ apart horizontally and 1′ apart vertically. Iron ties must always be coated with tar to prevent rust. They are not liable to be broken if the walls settle unequally, but are nevertheless unsuitable for India on account of their expansion from heat.

Hollow walls are seldom used in India, but there is no doubt that they would be useful in securing greater coolness for the interior of buildings. The solid brick wall becoming thoroughly heated up during a day, radiates the heat at night and so in hot weather the rooms never cool down. Hollow walls are naturally weaker than ordinary walls of the same thickness, and consequently are not suited for factories or Engineering works.

42. Reinforced brickwork.—Strips of hoop-iron about 1″ broad and 1/16″ thick are sometimes inserted in the horizontal joints (especially in half brick walls) when the bond of the brickwork is defective. The hoop-iron must be thoroughly protected from the action of the atmosphere lest it should rust and injure masonry; when it is used in thin walls it should be built into cement mortar. The strips should always be tarred and sanded before being used, and the ends should be bent, so as to hook on to one another at all the joints.

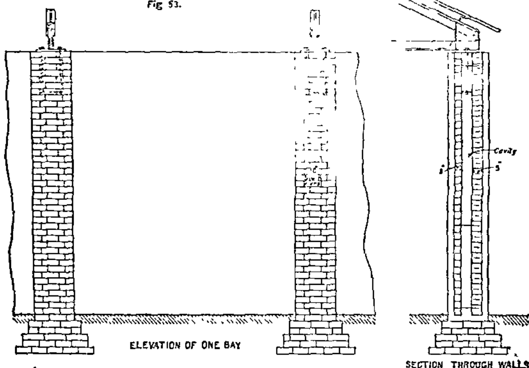

Fig 51.

*A superior method for reinforcing brickwork is to use galvanised steel wire netting of conical mesh in the horizontal courses of the brickwork when cement mortar is used.

Walls built on this principle are usually hollow, and consist of a 5″ flat brick outer wall, 1½ cavity, and a brick-on-edge inner wall. Such walls are said to give perfect insulation, to resist damp cold and heat, to maintain an even temperature, and also to shut out sound. A 4½″ thick wall

* Details supplied by Messrs. A. J. Main & Co, Calcutta.

built in cement and thus reinforced is said to be as strong as a 15" wall built in the ordinary manner, and a 3" reinforced wall to be as strong as an ordinary 9" wall.



For mill buildings, godowns and dwelling houses of single storey, walls are built with piers which are placed to correspond with the spacing of the trusses or the roof girders (*see* Fig. 53). The weight of the roof is then borne by the piers, which also carry the weight of the intermediate portions of the wall. Three inch reinforced walls are built in a similar manner for partition walls; they impose no loads on the floor and are self-supporting between the piers.

Black cotton soil is the most dangerous as a foundation for any masonry structure. The soil expands with the addition of moisture and contracts in the hot dry weather. Many methods have been tried for making foundations on this soil, but the only safe method is to excavate right through the layer of black cotton soil and found on good soil.

The expense of the deep foundations and the thick walls is heavy, so that the method described above of buildings piers and thin intermediate

walls which only rest on the piers will save much labour, and will frequently be found to be cheaper even though cement is still expensive in India. The high price of cement in India has so far prevented any extensive use of reinforced work, but several manufactories have lately been started in different parts of India with most satisfactory results, so that the price of cement is likely to fall, and this will enable reinforced work to be used on a much larger scale than is economical at present.

43. **Burnt brick in mud mortar.**—(Katcha-pukka masonry) is frequently used in India for reasons of economy, or when it is difficult to obtain lime. Most houses of one storey in height, and other light buildings, especially temporary buildings, are built with mud mortar. The method for the construction of these works is exactly the same as has already been described for works where lime mortar is used, and if they are carefully pointed they last nearly as long as works in which lime is used and the repairs required for them are not greater. The mud mortar should not be too rich either in clay or in sand, but an admixture of the two kinds of earth should be used. The addition of a little chopped straw and cow-dung improves the mortar.

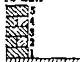
Lime mortar should always be used in foundation work up to plinth level, in archwork, for the top portion of walls, for cornices, corbelling and around doors and windows.

44. **Sun-dried bricks with mud mortar.**—(Katcha masonry) is frequently used for temporary buildings, and for the interior walls of larger buildings. The bricks are made of good brick earth, and are moulded and dried in the same manner as bricks which are intended to be burnt. The bond of katcha masonry is the same as is used in pukka masonry. The unburnt bricks crush easily, so this kind of masonry should never be heavily loaded, and must not be used for foundation work, for work within 1′ of the ground surface, or for the top parts of a wall, because the dampness of the soil and the rain is likely to destroy the bricks and ruin the structure. In such places burnt bricks with lime mortar should always be used.

In buildings above plinth level walls are frequently built with a face of burnt bricks in lime mortar and with a backing of sun-dried bricks laid in mud mortar. When this is done, the face is pointed with lime mortar, and the backing plastered with mud plaster.

Bricks always shrink when they are burnt, so when walls are made of a combination of burnt and sun-dried bricks, care should be taken to

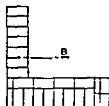
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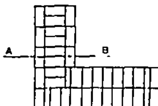
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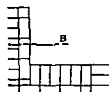
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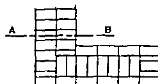
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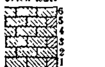
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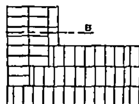
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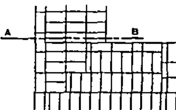
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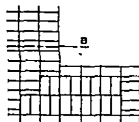
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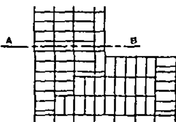
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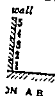
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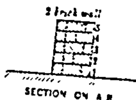


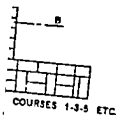
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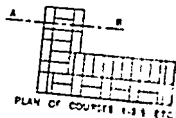
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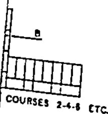
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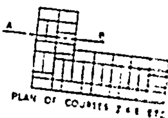


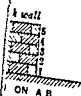


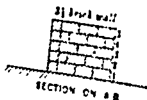


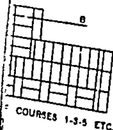


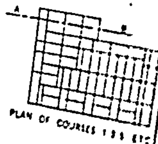


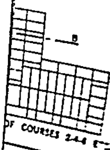


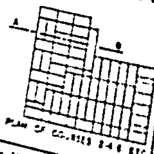












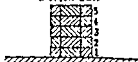
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k wall

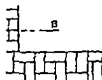


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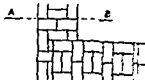
2 brick wall



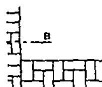
SECTION ON A B



COURSES 1-3-5 ETC



PLAN OF COURSES 1-3-5 ETC

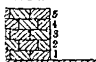


F COURSES 2-4-6 ETC



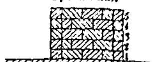
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ick wall

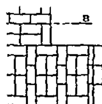


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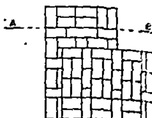
3½ brick wall



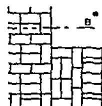
SECTION ON A B



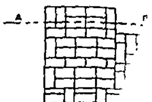
COURSES 1-3-5 ETC



PLAN OF COURSES 1-3-5 E



COURSES 2-4-6 ETC.



PLAN OF COURSE

HERRING-BONE BOND

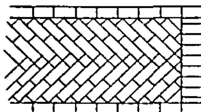


Fig. 46.

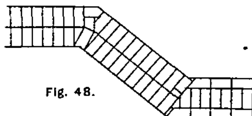


Fig. 48.

2-4-6 COURSES OF TWO 2 BRICK WALLS MEETING AT AN OBTUSE ANGLE.

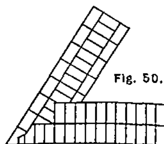


Fig. 50.

'ALLS

ACUTE ANGLE JUNCTIONS OF WALLS.

Photo Zinco. —No,6593-4,2000

use a smaller mould for the sun-dried bricks than is used for the burnt bricks, otherwise it will be impossible to make a proper bond.

45. Mud walls are built without bricks of any description. Large lumps of soft puddled clay are laid one on top of the other; these adhere to each other and form, when dry, one compact mass. The sun quickly dries the mud, and when one layer is dry another is added. These walls are generally built with a slight batter, and only good brick earth should be used. If the earth contains a large amount of clay the walls will crack and give trouble. When the walls are completed they are trimmed off carefully, and then plastered with a clayey earth in which chopped straw and cow-dung is mixed. These walls, if carefully built, will stand exposure to rain well.

Mud walls generally fail at the base from drift rain or drip from the roof. They should therefore be built out at the base for a foot or two in height, or (preferably) have a plinth of stone or burnt bricks with mud mortar.

46. Pisé walls are of brick earth which contains a small amount of moisture. This is excavated and broken up as finely as possible. It is then sifted through a ¼" mesh, and laid in thin layers, from 3" to 6" thick, between parallel boards which form the front and back faces of the wall. The earth is then tightly rammed, and fresh layers laid on the last layer till the top of the boarding is reached. The boarding is then removed and fixed in position for another portion of the work. When the earth is being rammed it will often be found advisable to add a little water to it. An ordinary watering can with a rose fixed to the spout is the most convenient method for doing this. This kind of work is more expensive than ordinary mud walls described in paragraph 45, and has no advantage over them, except that it looks better.

CHAPTER V.

ARCHWORK.

47. **Arches.**—An arch is an arrangement of wedge-shaped blocks, mutually supporting each other; it is built in the form of a curve, and supported at both ends by abutments or piers.

Certain forces act on each joint of the blocks (or voussoirs) of an arch. The joint divides the structure into two segments, and the forces which act on the upper of the two segments must be considered. These forces are the weight of the blocks in the upper segment, the weight of the superstructure on these blocks, and the load which is carried by these blocks.

The *centre of pressure* of each joint is where the resultant of the forces mentioned above cuts the joint.

The polygon formed by the intersection of the lines of action of the resultants mentioned above is called the *polygon of pressures*, and a continuous curve drawn to touch the sides of that polygon is called the *curve of pressures* or *line of pressures*. The polygon formed by joining the centres of pressure of the different joints is called the *polygon of centre of pressures*, and a continuous curve drawn through the centres of pressure is called the *line of resistance*. If the joints were indefinitely near each other the two polygons would coincide and become one curve.

Joints of rupture are those where the line of resistance is nearest to the intrados or extrados of the arch.

It is at these joints that the failure of the arch is to be apprehended as it is here that the joints tend to open. If the arch were built of perfectly incompressible and infinitely strong materials, it would be stable if the line of resistance touched the intrados and extrados respectively at the joints of rupture. But materials are compressible and have only a finite strength; it therefore becomes a necessary condition of strength as well as stability that the centre of pressure of a joint of rupture should not approach nearer to the edge of that joint than a certain limiting distance, and in archwork this is generally taken as one-fourth of the width of the joint.

Sometimes the edges of the voussoirs near each joint of rupture are rounded, so that as the arch settles the voussoirs will roll slightly on the converse surface. In this case the gaping of the joint would be slight,

but this can be pointed when the arch has thoroughly settled. The best and strongest stones should be reserved for the voussoirs in the neighbourhood of the joints of rupture.

From the calculation of the line of resistance (*see* applied mechanics) it can be ascertained whether the thickness of the arch is sufficient, and the line of resistance determines the line of action, and the amount of the resultant thrust acting on the abutment. Till this is known the dimensions of the abutment cannot be determined. For small works the line of resistance is seldom calculated, as for them it is best to study existing works and adopt dimensions which have been found satisfactory. An arch built so that the line of resistance was centrally situated, would stand even though no mortar were used in its construction, and even if the voussoirs were highly polished on their bearing surfaces. In practice, however, the extent of the surfaces of the arch joints, their friction and the tenacity of the mortar between them renders a departure in the form of an arch from the true line of resistance, unimportant within certain limits. In heavy or large arches, however, it is advisable to avoid any approach to the degree of compression which the materials employed are incapable of enduring, and consequently the best form should always be calculated (*see* details given in applied mechanics). If this is not done, there is either danger of the arch collapsing or of a waste of material.

Again, it must be remembered that in all permanent masonry structures, a suitable allowance must be made for unknown factors, such as storms, earthquakes, floods and the deterioration of the materials employed.

The important points to be observed in the construction of an arch are briefly abstracted below :—

(1) That there should be sufficient weight and strength in the abutments to safely resist the overturning moments of the thrust of the arch.

(2) That there should be sufficient area in the pier and arch to prevent failure by crushing.

(3) That there should be a sufficient thickness to prevent the superimposed load and weight from crippling the arch, or in other words, the centre of pressure at all joints should lie within the middle half of the arch. (Rankine even *considers* that it should lie within the middle third.)

(4) That the line of action of the resultant pressure on each joint should not be inclined at more than a certain angle with the normal to the joint. The angle is that whose tangent is $\frac{4}{5}$ths of the co-efficient of friction.

All bed joints should, therefore, be perpendicular to the line of resistance. In actual construction they are made *normal to the curve* of the arch, in which position they nearly approximate to normals of the line of resistance.

48. Arch Forms.—" An ideal arch would take the (inverted) form which the cables of a suspension bridge assume for the particular conditions of loading which are imposed; for then the horizontal reactions at the abutments will relieve the arch ring of any bending moments whatsoever, the stresses throughout being purely of axial compression. Such arches are called linear * arches."

There are numerous types of arches, named from the shape of the intrados, such as semicircular, segmental, Gothic or pointed arches, elliptical, oval, parabolic, and catenarian, etc. The form which is selected for any particular site depends on the nature of the loading and of the obstacle to be arched. The form of curve which is selected will affect the thickness of the arch ring and the economy of the whole structure.

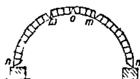
49. Circular Arches consist of two types, the *semicircular* and the *segmental*, where the intrados is less than a semicircle. The segmental is not quite as strong as the semicircular, but is suitable for long spans and is the type most commonly used in Engineering works. It has the advantage of not bulging upwards, or being depressed at the haunches when subjected to live concentrated loads. A segmental arch may subtend a central angle from 60° to 120°, but a 90° arch which gives a rise of $\frac{1}{5}$th span is recommended for most works. In semicircular bridges the bulging at the haunches must be guarded against by suitable spandrel filling.

From observations of the manner in which large circular arches settle, and from experiments made on a small scale, it appears that in all cases of unloaded arches (where the rise is not greater than the half span) they yield by the crown of the arch falling inwards and by the thrusting of the lower portions outwards, presenting five *joints of rupture*, one at the key-stone, one on each side of it, which limit the portions

* Frye's Engineering Pocket Book.

that fall inwards, and one on each side near the springing lines, which limit the parts thrust outwards.

Fig 54.

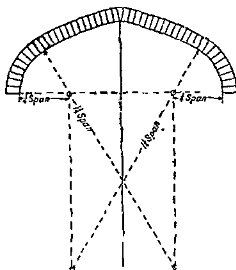


The figure represents the manner in which such arches yield by rupture: *o*, joint of rupture at the key-stone: *mm*, joints of rupture below the keystone: *nn*, joints of rupture at springing lines.

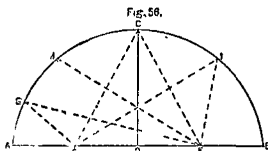
50. The Gothic or pointed arch has an intrados which is formed by two equal arcs with radii greater than half the span. This type of arch is seldom used in Engineering works. These arches yield by the lower portions falling inwards and thrusting the parts near the crown upwards and outwards.

51. Four-centred Tudor arch.—This is considered a graceful form of arch, but is only used in architectural work. Figure shows the method of describing the arch.

Fig 55

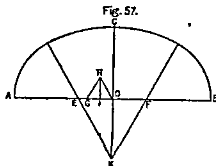


52. Semi-elliptical arch.—To set out a semi-elliptical arch, draw a line *A B* equal to the span or transverse axis of the ellipse. On this at right angles draw *C D* equal to the rise. Then from the vertex *C*, with



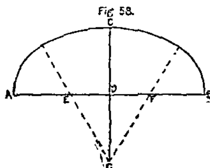
radius $A\ D$ or $D\ B$ equal to half the span, describe an arc intersecting $A\ B$ in E and F. These two points will be the foci of the ellipse. If two nails or pegs be fixed in the foci, and a line attached to them equal in length to $A\ B$, then the curve traced by a nail keeping this line stretched will be the ellipse required; the lines $E\ G\ F$, $E\ H\ F$, $E\ I\ F$, etc., being all equal to the span $A\ B$ and to each other.

53. Many-centred circular or oval arch curves formed of arcs of circles of unequal radii, and similar in appearance to the ellipse, are sometimes adopted for the arches of bridges; with the same rise and span they may be constructed to give a greater waterway than segmental arches, and in stone bridges they have been preferred by practical stone cutters, but in brick bridges they have no advantage in simplicity over elliptical arches. They may be described either with three, five or other odd number of centres. The number of centres will depend on the relation between the span and rise, when the latter is one-third, or a greater fractional part of the former, three centres may be used, but if the rise is less than one-third of the span, then five or a greater odd number must be taken. In practice it will be found troublesome to describe arcs from a large number of centres, nor indeed will occasion be found for using curves of this description. The following is a method of describing a curve composed of three arcs, each of 60°. Let $A\ B$ (*see* Fig. 57) represent the span and $C\ D$ the rise, take $D\ G = A\ D - D\ C$, and on it describe an equilateral triangle $D\ G\ H$,



let fall the perpendicular HI and take $IE = HI$. In the same way the point F is found. On $E F$ describe the equilateral triangle EFK, then E, F and K will be the centres required.

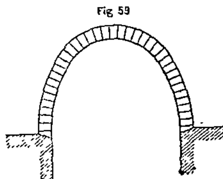
If the oval arch rise one-third, bisect the half spans $A D$ and $D B$ (*see* Fig. 58) in the points E and F, and produce versed sine $C D$ to G making

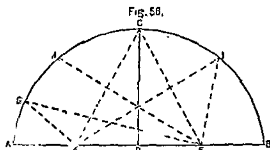


$D G = D C$, then E, F, and G, will be the three centres with which the curve may be described. In setting out arches the practical difficulty arises from the elasticity of string. Instead of a string, soft wire, about a tenth of an inch in diameter, should be used. When the radius does not exceed 12 or 15 feet, a slip of wood may be used with a nail at each end.

In oval arches the rise is seldom less than 1/3 of the span. American Engineers recommend the 3-centred oval arch as the best form to use for spans of ashlar work up to 200', and the 5-centred arch for greater spans.

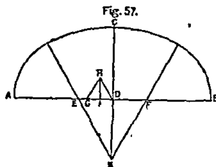
54. The parabolic arch is used when a vertical space greater than the span is required within the arch.





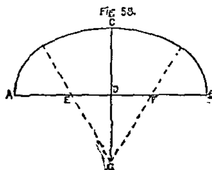
radius $A\ D$ or $D\ B$ equal to half the span, describe an arc intersecting $A\ B$ in E and F. These two points will be the foci of the ellipse. If two nails or pegs be fixed in the foci, and a line attached to them equal in length to $A\ B$, then the curve traced by a nail keeping this line stretched will be the ellipse required; the lines $E\ G\ F$, $E\ H\ F$, $E\ I\ F$, etc., being all equal to the span $A\ B$ and to each other.

53. **Many-centred circular or oval arch** curves formed of arcs of circles of unequal radii, and similar in appearance to the ellipse, are sometimes adopted for the arches of bridges; with the same rise and span they may be constructed to give a greater waterway than segmental arches, and in stone bridges they have been preferred by practical stone cutters, but in brick bridges they have no advantage in simplicity over elliptical arches. They may be described either with three, five or other odd number of centres. The number of centres will depend on the relation between the span and rise, when the latter is one-third, or a greater fractional part of the former, three centres may be used, but if the rise is less than one-third of the span, then five or a greater odd number must be taken. In practice it will be found troublesome to describe arcs from a large number of centres, nor indeed will occasion be found for using curves of this description. The following is a method of describing a curve composed of three arcs, each of 60°. Let $A\ B$ (*see* Fig. 57) represent the span and $C\ D$ the rise, take $D\ G = A\ D - D\ C$, and on it describe an equilateral triangle $D\ G\ H$,



let fall the perpendicular HI and take $IE = HI$. In the same way the point F is found. On $E F$ describe the equilateral triangle EFK, then E, F and K will be the centres required.

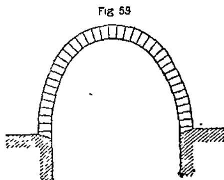
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$D G = D C$, then E, F, and G, will be the three centres with which the curve may be described. In setting out arches the practical difficulty arises from the elasticity of string. Instead of a string, soft wire, about a tenth of an inch in diameter, should be used. When the radius does not exceed 12 or 15 feet, a slip of wood may be used with a nail at each end.

In oval arches the rise is seldom less than 1/3 of the span. American Engineers recommend the 3-centred oval arch as the best form to use for spans of ashlar work up to 200′, and the 5-centred arch for greater spans.

54. The parabolic arch is used when a vertical space greater than the span is required within the arch.


Fig 59

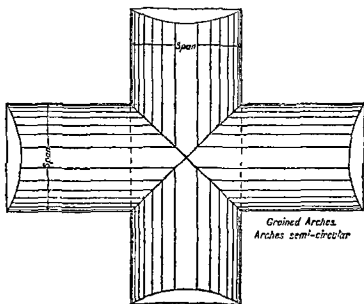
In concrete arches the elliptical arc may be used for any length of span, and the semi-ellipse for any length of span where the rise is considerable.

Inverted arches or inverts are similar to ordinary segmental arches, but are built *with the curve downwards*. They are built under openings in order to distribute the superincumbent weight equally over the substructure or along the foundation, as the case may be. They are also sometimes used where there is an upward pressure from springs.

Other unimportant kinds of arches are the stilted arch, the skew arch (*see* paragraph 68), the groined arch, and the straight arch.

Groined arches are those which intersect one another (*see* figure).

Fig 60.

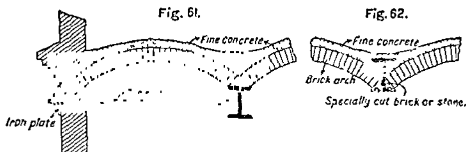


Flat or straight arches are used instead of wood or stone lintels over square-headed doors and windows. They are generally a brick and a half thick, and the bricks should be carefully cut or moulded to shape and set in the best mortar. They must always have semi-circular or segmental *relieving* arches over them. The extrados of the flat arch is horizontal, but the intrados is often given a camber of 1/8" per foot of span to counteract any settlement and correct the apparent sagging of a horizontal line.

A stilted arch is one that does not spring direct from the pier or abutment, but is raised as it were on stilts for some distance above them.

55. **Jack arches** are small span segmental arches which rest on steel beams or girders in place of masonry piers, and are frequently used for roofs, for floors of factories and road and railway bridges, etc. They are easy and cheap to build, but their use for floors and bridge decking has diminished since reinforced concrete work has come into common use.

The arches sometimes spring from the top flange of the rolled steel beams, sometimes from the lower flanges (*see* Fig. 61 and 62). The opinion of Engineers varies greatly as to which of these two is the better method; but there are many advantages in the first, and the only disadvantages are that perhaps it does not look so well as the second and that in buildings birds and bats find a resting place on the lower flange and render a house that is not in constant use very offensive.



In Fig. 61 the arches spring from a properly shaped skew-back, while in Fig. 62 a bad joint is made with the steel girder, the girder is more likely to be affected by changes in the temperature, and any marked expansion or contraction is bound at best to cause cracks and a leaky joint.

Four feet to six feet is the best span for Jack arches; they should never be made with a greater span than 8'. For roofs the brick arch is generally segmental, with a rise of 1/5 span and half brick thick. This should be covered with fine concrete from 3" to 6" thick.

Floors may be made with one brick arches, and the top surface levelled off with ordinary concrete.

When the arches spring from the top flange, the centres are rested on the lower flanges, and they can easily be fixed and removed. When the arches spring from the lower flange, the centering, which is generally slung from the lower flange, is more difficult and less satisfactory.

At the end of a series of Jack arches tie rods must be used to neutralise the thrust on the outer wall, which is seldom strong enough to stand the accumulated thrust of all the arches (*see* Fig. 61).

56. **Piers for arches.**—A pier should be of such a thickness that the two arches can spring clear without intersecting each other. In a long series of arches it is advisable to make at least every fourth or fifth pier an abutment pier (that is a pier which has sufficient stability to act as an abutment), so that the whole work may not be wrecked if one of the arches is seriously damaged.

* "Each pier of a series of arches ought also to have sufficient stability to resist the thrust which acts upon it when one only of the arches which springs from it is loaded with a travelling load."

The thickness of piers is generally made from $\frac{1}{6}$th to $\frac{1}{8}$th of the span of the arch.

High piers can frequently be cheapened by building them hollow, or by making archways through them, with inverted arches at the base.

57. **Domes.**—Doomed roofs are frequently built in India, but their construction refers more to buildings than masonry, and consequently details will be found in the building sections.

Syrian roof.—This roof is made with a specially moulded hollow brick. The arch is light and consequently the supporting walls and the centres can be reduced in strength. This type of roof is seldom used, so, further details are not given.

Sindh roof.—This roof is made with hollow horizontal tiles. It is only suited for localities where the rainfall is very light, and is seldom used.

58. **Underground arches, Tunnels, Culverts.**—In an underground archway or tunnel, special attention must be paid to the material or soil in which it is to be built. If this is very loose and liable to slip, there will be pressure on the walls as well as on the arch and even on the bottom and therefore the cross section of the masonry should more or less approach to the cylindrical, in which form it would need to be made in the loosest material or in water. The calculations must depend on the conditions and are not gone into here, the need for them only being noted.

It appears that in the brickwork of various existing tunnels the factor of safety is as low as four. This is sufficient, because of the steadiness of the load; but in buried archways exposed to shocks, like those of culverts under high embankments, the factor of safety should be greater, say from eight to ten.

* Rankine's Civil Engineering.

59. The mason, in order to put a design into execution, must set out the arch full size in elevation on a levelled surface with the joints marked thereon. The next process is to make the moulds for which thin sheets of zinc are best adapted, the zinc being cut to the form of the required sections of the voussoirs, both on the *bed* and on the *face*. Where arches are formed of one curve, and the voussoirs are all of one size and shape, one mould will be sufficient, except for the key-stone. The moulds being thus obtained and numbered or lettered for their respective situations, the stone is to be worked to a level face, and the face mould applied and marked, the joints worked and the section or bed mould applied and marked.

60. Theoretically the thickness of the arch should be greater at the springing than at the crown on account of the larger tangential thrust. Brick arches should be divided into several portions, and the increase of thickness in each portion should be half a brick or one brick in order to secure a proper load In actual practice, however, no difference is made in small arches. The thickness of arches depends on the rise of the span, on the weight supported and on the material of which the arch is composed. French writers give $\frac{1}{30}$th of the span + 1·1 foot.

Rankine's formula for the thickness of an arch at the crown which is adopted by most Engineers is :—

For single circular segmental arches thickness

$$= \sqrt{(\cdot 12 \times \text{radius at crown})} \text{ in feet.}$$

For single semi-circular and oval arches the co-efficient 0·12 should be increased to 0·2.

For segmental arches in series the thickness

$$= \sqrt{(0{\cdot}17 \times \text{radius at crown})} \text{ in feet,}$$

and for oval and semi-circular arches in series the co-efficient 0·17 should be increased to 0·25

For brickwork in rings about 12 per cent. should be added to the thickness calculated from the above figure.

The theoretical thickness at the springing varies from $1\frac{1}{2}$ times to twice the thickness at the crown, though there is seldom as much difference made in practice.

In America the following equations are commonly used.

For highway bridges thickness at crown in feet.

$$= \sqrt{0{\cdot}01 \text{ span} \left(\frac{\text{span}}{\text{rise}} + 3\right)} + 0{\cdot}15.$$

For railroads $= \sqrt{\cdot 01 \text{ span} \left(\frac{\text{span}}{\text{rise}} + 4\right)} + 0{\cdot}20.$

For high railroads $= \sqrt{0{\cdot}01 \text{ span} \left(\frac{\text{span}}{\text{rise}} + 5\right)} + 0{\cdot}25.$

Thickness at springing in feet =

thickness at crown $[1 + 0{\cdot}002 (\text{span} + 2 \times \text{rise})]$.

61. **Arch Centres.**—A centre is a temporary structure composed of wood, iron, earth, stone or brick, or a combination of these materials, by means of which the voussoirs of the arch are supported until the work is completed and capable of supporting itself. When the arch is completed the temporary structure is removed.

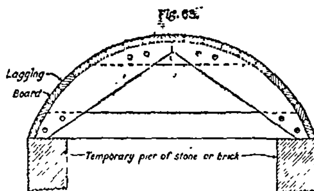
Wood or iron centres are seldom used in India for small unimportant arches, but wooden centres are generally used where the span is large, the work important, and especially when there are a series of spans to be arched. In all kinds of centres the two chief points to attend to are—

(1) The upper or bearing surface should be correctly shaped to agree with the design of the arch.

(2) The centering should be strong enough to bear the weight of the arch, of the materials and of the workmen, etc., which may be placed on it, without sinking or changing its form at any time during the construction of the arch.

Wooden centerings consist of ribs or trusses the upper outline of which is of exactly the same form as the intrados of the arch to be supported. These ribs or trusses are placed from 5′ to 6′ apart, and connected by boards called *laggings* upon which are laid the stones or bricks of the arch.

The construction of wooden centres for small arches requires but little skill. The ribs are made with two or more thicknesses of planks nailed together with the grain of the wood in alternate planks crossing one another (*see* Fig. 62).



The centres required for large arches and the methods used in lowering and removing them (commonly called *striking*) are described under the section "Carpentry."

For long lengths of arching it is customary to construct a 10′ or 12′ length of centering, consisting of three ribs fastened together with the lagging boards. When this length of arch is completed, the centering is struck and moved forward for nearly its whole length, leaving a few inches of the part completed underneath to make a good joint. It is then properly fixed at the correct level in this new position and a second portion of arch work is now built upon it. After this it is again struck and the process is repeated till the arch is finished.

The Indian workman is very clever in making rough centerings for small span arches. They are quite good enough for most purposes, are cheaper than wooden centerings and can easily be removed when the arch is completed.

For low bridges and culverts the usual method of construction is to build rough walls of brick or stone in mud at both ends of the work, and then fill in the space between the walls with well rammed earth. The top is then curved off nearly to the correct shape of the arch, and plastered with mud or lime mortar. When the work is completed the end walls are pulled down and the earth removed.

The method of making rough centerings for arches in houses is by building two or more piers of brickwork in mud and laying rough timbers or bamboos on them. On this platform the same process will be repeated, and then the shape of the arch may be made with small pieces of stone or bricks and mud, and the structure may finally be covered with lime plaster to give it the correct shape for the arch.

The great objection to these kinds of rough centerings is that the shape is very liable to become distorted due to the workmen moving about on top, and also to the settling of the earth as a result of the water used on the masonry itself.

62. Various opinions have been expressed as to the period that should lapse between the keying and the uncentering of arches, though there is a concensus of opinion that immediately after the completion of the arch the centerings should be slacked a little, so that the bricks may close in and compress the mortar. Undoubtedly this should be done before the facing, spandrel and outside parapet walls are built upon the arches. A trifling change of form in the arch might occur by its settle-

ment without in any way impairing its strength, but such a settlement would probably crack and disfigure the external face walls if they had already been built. Arches have been known to have been safely uncentered immediately after keying, and yet to have changed their shape but slightly; also centerings have been left up one, two or even six months and though on their removal the arches have not sunk at all, they have occasionally cracked after the addition of the weight of the superstructure. It is clear that any change of shape in the arch must be less prejudicial to its strength while the mortar is soft than after it has set, for should any settlement *then* take place, the work must become crippled.

When, however, a large arch has been built on a solid centering, or on one that cannot be properly and equally lowered, it may be advisable to allow the arch to set, at least partially, before proceeding to remove such a centering.

The length of time which it has taken to build the arch is an important factor in this question. If the lower part of the arch from the springing has been made some time before the upper part it will have set, and then, if the centre is struck directly the arch is keyed, the compression of the soft part will very likely cause cracks in the hardened part. But if the work has been evenly and quickly done, and kept thoroughly moist (as it should be), then no doubt a gentle slight lowering of the centres is the correct thing, to allow the arch to be slightly compressed and to bring all its joints into fair bearing. This lowering should not be done while the mortar in the last finished joints is still so soft that it might be squeezed out.

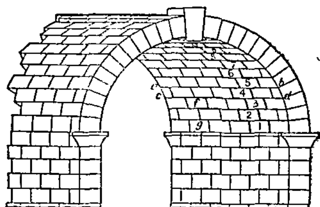
In conclusion it may be said that it is better to remove the centres quickly than to leave them too long, to wait till the mortar is firm than to wait till it has hardened.

• The centre of an arch should not be struck till the backing has been built and the mortar is no longer shaky. Again where an arch is one of a series of arches, with piers between them, no centre can be struck till the next arch is well advanced, unless the pier is what is called an abutment pier.

63. **Bond of stone arches.**—The same general principle is followed in arranging the joints and bond of the masonry of arches as in other structures of cut stone. The beds should be perpendicular to the [illegible] tion of the thrust, though the arch ring and the [illegible] joints [illegible] be normal to the beds and to the surface of t[illegible] and the

any two systems of joints should be normal to each other at their lines of intersection.

Fig 64.



In semi-circular and segmental arches the voussoirs are equally made of the same breadth, measured along the soffit. The joints of each course of voussoirs between the faces of the arch are made continuous, each of these courses being termed *a string course* (as course *b a c d*), and their joints *coursing joints* (as each of the joints *b a* or *d c*). The planes of the joints along the soffit are not continuous, but break joint; the stones which correspond to two consecutive series of these joints being termed a *Ring course* (as the ring of stones 1, 2, . . . 10, shown with dark lines in the figures), and its joints *heading joints* (as joint *f g* in figure). By this combination of the ring and string courses, the fitting of the blocks, the settling of the courses and the bond are arranged in the best manner.

64. Bond of brick arches.—Brick is the material most usually employed in India for the construction of arches. The principles of construction are the same both in stone and brick, but in using the former every voussoir has to be cut to an exact form, with a depth proportionate to the weight of the arch and its superincumbent load.

In brick arches also the general direction of each joint should be perpendicular to a tangent to the curve at that joint.

The simplest approximate method of keeping the joints in their proper direction is by the use of pieces of hard board of from 1 to 1½ feet in length. These are cut out to the curve of the arch on their lower edge, whilst their sides, made perpendicular to this curve, show the direction of the joints.

65. Since the crushing strength of granite and of good varieties of lime and sandstone is greater than that of the best bricks, stone should be used when available in preference to bricks for arches of all large spans.

Considerable difference of opinion exists among Engineers regarding the best method of laying the bricks in a brick arch.

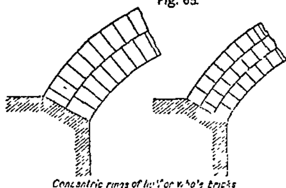
The three principal methods of bonding brick arches are shown in figs. 65, 66 and 67, namely :—

(*a*) Concentric rings of whole or half bricks (*see* Fig. 65).

(*b*) Alternate rings of whole and half bricks, sometimes called header and stretcher bond (*see* Fig. 66).

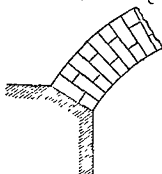
(*c*) Block in course bond (*see* Fig. 67).

Fig. 65.



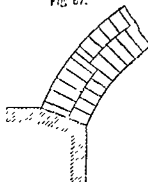
Concentric rings of half or whole bricks

Fig 66.



Alternate rings of half and whole bricks.

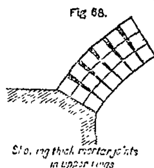
Fig 67.



Block in course bond

In the first method (see Fig. 65), the bricks are laid in section as stretchers or headers in concentric rings. The average thickness of joint is least in this method, and consequently more bricks and less mortar are used. It is the easiest method of construction, especially when the stretcher rings are used, and is used more often than any other method. A plan of the one brick ring arch corresponds to Heading Bond.

If radial joints were made continuous throughout the thickness of the arch as in Fig. 68, the mortar joints or the upper rings would be very thick, and in large arches might be unable to withstand the pressure upon



them, especially if the centerings were struck before the mortar had had set. In such cases the crown would settle down and the whole arch would be thrown out of shape, creating such unequal pressures as might cause its fall. Wedges of slate or stone are sometimes fixed in the thick mortar joint, but the practice is not recommended as it is liable to crack the brick and cause unequal pressure.

It is not recommended that brick arches of more than 30′ span should be built with concentric rings, because the line of pressure in passing from the extrados to the intrados tends to separate the rings, and the whole pressure might momentarily be sustained by a single ring. In this case the ring would probably be crushed, when the pressure would be transferred to the next ring, which might give way in a similar manner, and then the whole arch would fail.

On the other hand, there are many instances of large span railway arches which have been made of concentric brick rings and have been built successfully and have given no trouble. If bridges of large spans are made, great care must be taken to use only the best lime and bricks, and (if possible) cement mortar, in their construction.

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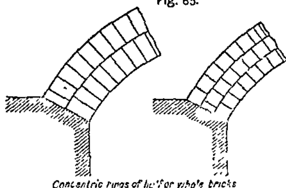


Fig. 65.

Concentric rings of half or whole bricks

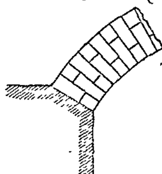


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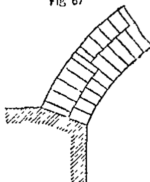
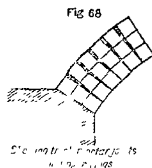


Fig 67

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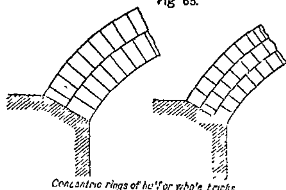
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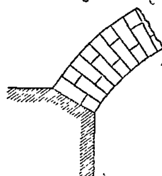
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Fig 65.



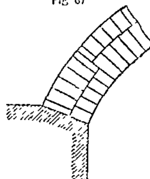
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Fig. 66.



Alternate rings of half and whole bricks

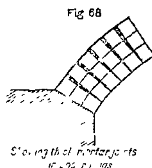
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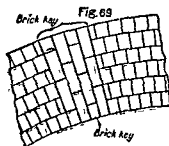
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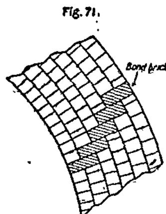
Sometimes bricks are specially moulded to suit the arch, with a greater thickness at one end than at the other, and then there is no increase of thickness of the mortar joint at the back of each ring. Still, with more than one ring the radial joints will not be continuous, as in Fig. 68, but broken as in Fig. 65. Such bricks are expensive to make, and in order to fully answer the intended purpose they must be made of several patterns so as to conform with the radii of the different rings.

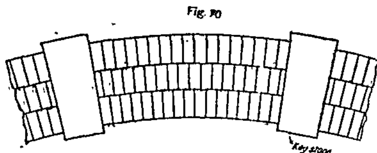
To avoid the objections mentioned above to concentric ring arches, it is customary to provide *keys* made of blocks of stone or of blocks of bricks of a different bond as are shown in Fig. 69, 70 and 71.

The proper position for the bond blocks is where the joints of the various rings coincide.

Another arrangement consists of introducing headers so as to unite two half brick rings whenever the joints of two such rings happen to coincide. The rings are sometimes united in consecutive pairs right through the thickness of the arch, *see* figure 70.

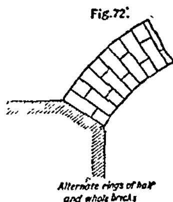






66. The second method of bonding brick arches mentioned in paragraph 65 is shown in Fig. 72.

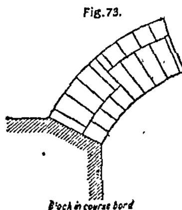
Fig. 72.



This consists of bricks laid alternately in section as headers and stretchers like Flemish Bond and with continuous radial joints. The plan consists of alternate courses of headers and stretchers similar to English Bond. The plan of a 1-brick arch can either be similar to English or Flemish Bond. The average thickness of joint is greater in this method than with concentric rings, and consequently more mortar and less bricks are required. Many people prefer the appearance of this bond to any other, and consequently it is largely used in the fronts of buildings.

67. The third method, shown in Fig. 73, is generally called block-in-course. This method of bonding aims at obtaining with bricks the wedge-

Fig. 73.

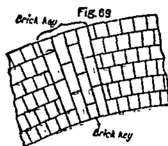


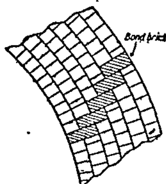
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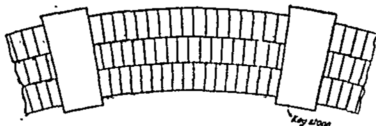
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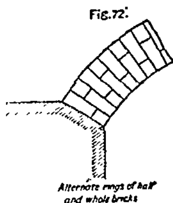
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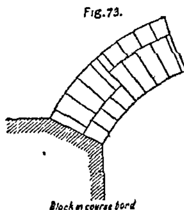


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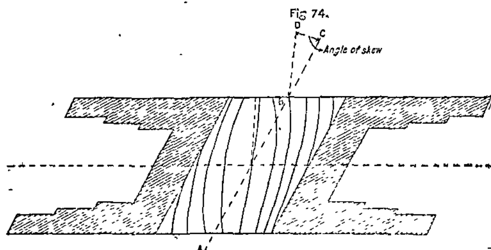
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67. The third method, shown in Fig. 73, is generally called block-in-course. This method of bonding aims at obtaining with bricks the wedge-



shaped voussoirs of the stone arch. The bricks are grouped in blocks which are bonded by continuous radial joints. Adjacent blocks are made of different bonds, but *any good bond may be used. This method is* seldom used in India.

68. **Oblique or skew arches.*** — When a road, railway or canal crosses any other such work in any direction except at right angles, a skew or oblique bridge will be required. Skew arches are of figures derived from those of symmetrical arches by distortion in a horizontal plane. The elevation of the face of a skew arch, and every vertical section parallel to its face, is similar to the corresponding elevation and vertical section of a symmetrical arch. The forces which act in a vertical layer or rib of a skew arch with its abutment are the same as those which act in an equally thick vertical layer of a symmetrical arch with its abutments, assuming it has the same dimensions and figure, and is similarly and equally loaded.



The angle of skew or obliquity is the angle which the axis of the archway, *i.e.*, $A\ C$, makes with the line at right angles to the face of the arch such as $B\ D$. $C\ B\ D$ will be the angle of skew. The span of the arch on the *square* is the perpendicular distance between the abutments, the span on the *skew* is parallel to the face of the arch.

A skew arch differs from an ordinary symmetrical arch in that the bed joints are not parallel to the abutments, but are placed as nearly as possible at right angles to the face of the arch, because the best position

* Parts of paragraphs 68 to 70 are copied from Rankine's Civil Engineering.

Fig. 76 Fig. 77. Fig. 78.

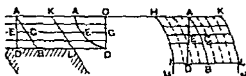


Fig. 80.



Fig 81.

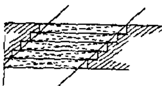


Photo. Zinco April, 1923 —No.8593-S 2000.

for the joint is perpendicular to the thrust along the arch. If they were placed parallel, it is clear that a large portion of the arch would have no abutment on one side and must fall. Joints of the best form are difficult to construct, so spiral joints are used in practice as an approximation. Skew arches are much easier to build with bricks than with stones, as with stones each voussoir has to be carefully cut to the correct shape.

69. Before a skew arch is constructed, a large scale drawing of the soffit must be prepared, showing the exact figure and position of each arch stone. That drawing represents the curved surface of the soffit, as if it were spread out flat, and is called the *development* of that curved surface. In general it is sufficient to draw one half of the soffit, the other half being similar. The following are the processes by which that drawing is prepared.

(1) **To draw the development of the soffit and of its vertical sections on the skew.**—Figure 76, Plate VI, represents the plan of one half of the arch, *H A K* being the crown of the soffit, and *I B L* the face of one of the abutments. The line *A C B* represents the position of a vertical section on the skew, and *A E D* perpendicular to *H K*, that of a vertical section on the square, the angle *B A D* being the angle of obliquity.

Assume any convenient number of points in *H I*, through which draw a set of lines parallel to *H K*, and also a set of lines at right angles to *H I*. Draw *O B* parallel to *H I* cutting the latter set of lines; and on *O B* as half span, construct the vertical section of the arch on the skew shown in Fig. 75, in which *A C B* is the line on the soffit corresponding to *A B* in Fig. 76. Then construct the vertical section on the square, Fig. 77, by drawing *O D* parallel to *A D* to represent the half span on the square, transferring the ordinates of Fig. 75 to the corresponding points in Fig. 77; for example *G E* is made equal to F C.

The development of the half soffit *H I L K* is constructed as follows:—

Produce the centre line of the soffit to *H A K* in Fig. 78, making the lengths *H A* and *A K* equal to *H A* and *A K* in Fig. 76. Then draw *A E D* at right angles to *H K*, and make *A E*, *A D*, etc., equal in length to the arcs *A E*, *A D*, etc., which are cut off on the curve *A E D* of Fig. 77 by its

several ordinates. Then will the straight line A E D in Fig. 78 be the development of the section on the square, corresponding to *A E D* in Figs. 76 and 77. Through the points of division of *A E D* in Fig. 78 draw lines parallel to *H K* such as *E C* and *I D*, *B L*, etc., on which lay off ordinates such as *E C*, *D B*, etc., equal respectively to the corresponding ordinates *E C*, *D B*, etc., in the plan Fig. 76, and through the ends of these ordinates draw a curve *A C B*, Fig. 78 ; this will be the development of the vertical section on the skew *A C B* Figs. 75 and 76.

Draw also the curves *H I*, *K L* parallel, similar and equal to *A C B*. Then *I H K L* will be the development of half the soffit. Draw *I M* and *L N* perpendicular to *I L*, then *M I L N* will be the development of part of the face of an abutment. Draw also any convenient number of intermediate curves, such as those shown by dotted lines, parallel, similar and equal to *A C B*, to represent the development of several parallel skew vertical sections of the soffit, and to indicate, at the same time, the direction of the thrust at each point which they traverse. These may be called *curves of pressure*.

(II) To draw on the development of the soffit, the bed joints and side joints of true courses.– The bed joints are drawn by sketching by free hand a series of curves, cutting all the curves of pressure at right angles, and called the *orthogonal trajectories of the curves of pressure*. The side joints being perpendicular to the bed joints are parts of curves of pressure themselves (*see* Fig. 80). The courses become thinner towards the acute angle of the abutment, and thicker towards the obtuse angle, so that it may be sometimes advisable to introduce intermediate bed joints near the obtuse angle, as shown near *L* in Fig. 80. In the figures the arch springs vertically from the abutments, so that none of the bed joints intersect the line of springing *I L*, to which they are all asymptotes. If the arch had been segmental some of the bed joints would have intersected that line obliquely, making necessary the use of skew backs of the kind shown in Fig. 79, but not so oblique.

(III) To draw on the development of the soffit, the bed joints and sine joints of spiral courses (*see* Fig. 79).—On the development of the soffit draw a series of parallel equidistant straight lines, perpendicular to the direction of the thrust at the crown of the arch; these will represent the bed joints, and the side joints will be perpendicular to them. Between *I* and *L* are shown the skew backs or stones which connect the starting courses of the arch with the horizontal courses of the abutment.

Spiral courses are perpendicular to the thrust at the crown of the arch only, and become more and more oblique to it the nearer they are to the springing.

70. **Ribbed skew arch.**—The difficulties attending the construction of skew arches are sometimes avoided by indenting the face of the abutments and building the arch in cylindrical rings (*see* Fig. 81), but though this has been successfully executed in many places, it is manifestly a make-shift and cannot be recommended.

CHAPTER VI.

MASONRY WORK IN FOUNDATIONS AND WELLS

71. The term *foundation* is used indifferently either of the lower courses of a structure of masonry or for the arrangement, whether natural or artificial, on which these courses rest, and which may be more precisely termed the *bed of the foundation.*

The strength and durability of structures of masonry depends greatly upon the bed of the foundation. In arranging this, regard must be had not only to the permanent pressure of the superstructures which the bed may have to support, but to that occasionally caused by wind, temperature, loading of floors, thrust of arches, roofs machinery, etc. The foundation bed should, in all cases, be placed so far below the surface of the soil that it will not be liable to be uncovered or exposed or unduly softened by the penetration of floods or rain water; and its surface should not only be normal of the resultant of the pressure which it sustains, but this resultant should intersect the base of the bed so far within it that the portion of the soil between this point of intersection and the outward edge of the base shall be broad enough to prevent its yielding from the increase of pressure thrown on it.

72. The object to be attained in the construction of any foundation is to form such a solid base for the superstructure that no movement shall take place after its erection. It must be remembered, however, that all masonry structures (whether brick or stone) will settle to a certain extent, and that, with a few exceptions, all soils will become compressed more or less under the weight of a building, however trifling its character. The aim, therefore, should be not so much to attempt to *prevent* settlement, as to ensure that this settlement should be *uniform.* *It cannot be too strongly impressed on the mind of the student that it is* not an *unyielding* but a *uniformly yielding* foundation that is required, and that it is not the *amount* so much as the *inequality* of settlement that does the mischief.

The second great principle in preparing foundations is to prevent the lateral escape of the supporting material.

The principles, therefore, to be kept in view in the treatment of all

cases where the natural soil is at all of a doubtful character, may be thus briefly stated :—

1st.—To distribute the weight of the structure evenly over a large area of bearing surface, and to keep the intensity of pressure within safe limits.

2nd.—To prevent the lateral escape of the supporting material.

73. **Nature of sub-soils.**—The first preliminary step to be taken, in determining the kind of bed required, is to ascertain the nature of the sub-soil on which the structure is to be erected. This may be done in ordinary cases and to ordinary depths by sinking a pit; but where the sub-soil is composed of various strata and the structure demands extra precaution, deep borings must be made with the tools usually employed for this purpose.

It is a common practice to carry down the foundations to a fixed depth irrespective of the soil strata. The result is that the structure is frequently founded on an inferior base; a cheaper and more satisfactory structure can sometimes be obtained by founding on a firm stratum higher up.

74. **Soils for Foundations** may be divided into three classes :—

The 1st class consists of soils which are incompressible or at least so slightly compressible as not to affect the stability of the heaviest masses laid upon them, and which, at the same time, do not yield in a lateral direction. Solid rock, compact stony soils, hard clay which yields only to the pick or to blasting belong to this class. Such soils will stand from 5 to 18 tons per square foot.

The 2nd class consists of soils which are incompressible, but require to be confined laterally, to prevent them from spreading out. Pure gravel and sand belong to this class. Such soils will stand from 3 to 5 tons per square foot.

The 3rd class consists of all the varieties of compressible soils, under which head may be arranged ordinary clay, the common earths, and marshy soils. Some of this class are found in a more or less compact state, and are compressible only to a certain extent, such as most of the varieties of clay and common earth. Such soils will stand from 1 to 2½ tons per square foot. Others are found in an almost fluid state, and yield with facility in every direction. Such soils will only stand from ¼ to 1 ton per square foot.

The London County Council Regulations are that the pressures of foundations on the natural ground shall not exceed the following :—

Soft clay or wet or loose sand—1 ton per square foot.

Ordinary clay or confined sand—2 tons per square foot.

Compact gravel, blue clay or chalk— 4 tons per square foot.

75. Rock.—To prepare the bed for a foundation on *rock* the thickness of the stratum of rock should first be ascertained (if there are any doubts respecting it); and if there is any reason to suppose that the stratum has not sufficient strength to bear the weight of the structure, it should be tested by a trial weight, at least twice as great as the one it will have to bear permanently. The rock is next properly prepared to receive the foundation courses by levelling and filling the inequalities with fine concrete or stepping, so that its plane or planes are normal to the acting forces. All perishable or disintegrated material should be removed, and the exposed surface should be roughened, if necessary, to prevent sliding of the superstructure. This is specially necessary in the case of dams which are often founded on rock which has been polished by the action of the silt or stones carried by the water. If fissures or cavities are met with of so great an extent as to render the filling of them with masonry too expensive, an arch may be formed, resting on the two sides of the fissures, to support that part of the structure above it. This treatment is not suitable for dams, where all dykes and fissures should be opened out and refilled with good concrete, not only under the dam itself, but for a considerable distance upstream and a short distance downstream of it.

76. Hard earths.—In stony earths and in hard clay the bed is prepared by digging a trench wide enough to receive the foundations, and deep enough to reach the compact soil which has not been injured by the action of frost or heavy rain; a trench from 4 to 6 feet will generally be deep enough for this purpose for the heaviest buildings, but ordinary one-storey houses can be given shallower foundations.

In compact gravel and sand, where there is no liability of lateral yielding, either from the action of rain or from any other cause, the bed may be prepared as in the case of stony earths. If, however, there is any danger of lateral yielding, the soil on which the foundation is to rest must be secured by confining it laterally by means of sheeting piles, or in any other way that will offer sufficient security.

77 Black cotton soils.—In many parts of India soils are found which contain a large percentage of clay, and are commonly called black cotton soil. There are several varieties of this soil, but all expand or contract to a greater or less degree when moisture is added or removed, and are unsuitable for foundation beds unless some special precautions are taken. Even then they should be avoided if possible.

If the black soil stratum is a shallow one (as frequently happens), the foundations should be carried right through the upper layer and bedded on the good soil underneath. Sometimes, however, the black cotton stratum is deep, and it would be very costly to carry the masonry right through it. In such cases the pit is generally excavated right through the black cotton soil and refilled with thoroughly rammed ballast or sand and the masonry structure built on top.

Sometimes the whole of the soil is removed for a few feet in depth, and a concrete platform with or without reinforcement built right across the building, and on this platform the masonry walls are constructed.

Other methods are to reduce the intensity of pressure to a low figure by means of broad footings, and built either on the soil or on a small depth of sand or ballast.

Whatever system is however adopted, it is absolutely necessary to take the foundations down deeper than are necessary in other soils, so as to obtain a foundation bed which is outside atmospheric influences.

78. **Compressible earth.**—The beds of foundations in compressible soils require peculiar care, particularly when the soil is not homogeneous, presenting more resistance to pressure in one point than in another; for, in that case, it will be very difficult to guard against unequal settlement.

In ordinary clay or earth it is customary to dig a trench to the width of the foundation, and the bottom of the trench is then levelled off and the concrete laid.

Before any concrete work commences, it is advisable to soak the bottom of the bed with water and dig out any holes or cavities which this shows up. The bed should then be thoroughly rammed and consolidated, and all holes filled with concrete before the concrete foundations are commenced.

There are, however, many objections to the excavation of a trench of the same width as the concrete, because the full width of the concrete edges cannot be rammed without disturbing the earth sides, and the edges of the concrete remain poor and spongey. Where the soil is not stiff, it is frequently necessary to hold up the sides of the trench with boards or other means; the system is then not so objectionable.

A better method is to dig a wide trench and lay the concrete as is shown in Fig. 126 of paragraph 127. This method enables the sides of the concrete to be rammed, and also gives a better bearing surface.

79. **Wet soils.**—The arrangements for building the foundations

when there are springs in the excavation pit, are necessarily of great variety and vary according to circumstances. If the springs are confined to certain points they may be treated by introducing vertical pipes or building masonry cylinders, or even, if clear of the actual foundations, an earthen dam round them, to the height to which the water will rise, or to which it can be kept down by pumping from the cylinders. By such means the foundation pit can be kept dry and the work carried on easily: but this can only be done when the pipes or cylinders can be made with a water-tight connection with the bottom of the foundation, so that the water can only rise in them and not into the pit. When the foundation masonry has been put in and has set, the pipes or cylinders can be plugged tight at foundation level, and the upper part cut off. The water is then confined under the foundation.

When, however, the water rises all over the foundation pit, the procedure mentioned above would be impossible. The general custom is then, after pumping down to ground level, to provide a system of channels well outside the concrete by which the water can be led to a pit or sumph, as it is called, in which the pump works. The sumph will of course be deeper than the foundation level, so that by pumping, or by ordinary lifts, the level of the water can be reduced below the level at which the masonry or concrete has to be laid. Sometimes the channels noted above are mere excavations, but if the soil is loose they may have to be made of pipes with slits or perforations for entrance of the water.

An endless variety of arrangements may be adopted, but generally one or other of the two plans noted above are adopted, *i.e.*, either to isolate the springs and choke them with their own rise, or to pump or drain down to a certain level, by making free drainage to a lower point than the bed, and either pump that level down or provide a natural overflow from it to some lower ground. The first method has many advantages, in that the spring level has not to be reduced as low as in the other. In this connection may be mentioned a plan that was successfully used on the Sirhind Canal Works, where the springs threw up sand, or the pumping drew it up. The springs were partially choked by pouring into them much coarser sand, which was too heavy for the velocity of the spring to move, and yet allowed the water a free passage. It was not possible to choke the springs altogether, as when this was tried they broke out in other places.

Considerable trouble is frequently experienced in preventing the earthen sides of the foundation pit in wet soil from sloping forward and tumbling into the pit. Whenever possible it is advisable to give very easy slopes depending on the nature of the soil such as 2 or 3 to 1 above spring level, and 4 to 8 to 1 below spring level; but when this cannot be done, the earth must be supported by piling, walls or other expedients.

80. Foundations have frequently been made with complete success in wet and marshy soils, some of the methods adopted are—

(*a*) Make a platform of concrete, or reinforced concrete, of such a width that the masonry superstructure which is built on it will only give a very small intensity of pressure such as the soil may be expected to bear.

(*b*) When a firm stratum of soil exists at a small depth, the marshy soil may be removed and the trench refilled with concrete; or piles may be driven down to the hard earth and a platform of reinforced concrete or planks constructed on top of the piles on which the superstructure is built.

(*c*) When the depth of the marshy soil is considerable, the simplest method is to drive in reinforced concrete piles of such a number and depth that they are able to bear the superstructure. On top of the piles a platform of reinforced concrete is built.

(*d*) Drive sheet piles down to hard bottom, but not necessarily into it, so as to enclose a circular or rectangular mass of soil. On top of this hurdles or faggots are laid, and over these a timber platform is constructed. Or in place of the hurdles and timber platform, a better method is to build a reinforced concrete top. The stability of the structure depends entirely on the power which the sheet piles possess of resisting pressure from within, and consequently this method is seldom used.

(*e*) Another method which is said to give good results, where the ground, though soft, is of tolerable consistency, is to bore holes with a large augur to a considerable depth, and then to fill them up with sand. The sand acts almost as a fluid and distributes the pressure over a large area, and does not injure the ground by vibration.

81. Piles are made in numerous shapes and of different materials, but wood is the usual material used in ordinary works, though for

permanency reinforced concrete or steel piles are the best, and are year by year being used in larger numbers. Ordinary wooden piles may be circular or squared and are generally from 9″ to 18″ diameter, with a length not greater than 20 times the diameter, otherwise they are liable to be bent during the process of driving. For important works squared timber is generally used, but if saplings or rough timber is used. they should be prepared for driving by stripping them of their bark, and paring down the knots, so that the friction in driving may be reduced as much as possible.

To prevent the head of a pile from being split up by the blows of the ram, it is customary to fit on a strong hoop of wrought-iron. The foot of the pile is also generally fitted with a wrought or cast-iron shoe of suitable shape and fastened with spikes or bolts.

82. Sheet piles are very commonly used in wet ground or in water to form a vertical, or nearly vertical, sheet for the purpose of preventing the materials of a foundation from spreading, or to obtain a more or less water-tight compartment for the construction of the masonry work.

Sheet piles are made of many different forms, the thickness varying from 2″ to 12″; some of the commoner forms are shown in figures 82 to 86.

Fig. 82.



Fig 83.

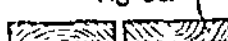


Fig. 84.



Fig. 85.

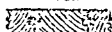
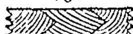


Fig. 86.



The bottom ends of the piles are generally cut on the slant so that in driving they will push against those already driven home and make a close joint. Sheet piles are usually driven between girders or horizontal waling pieces which are supported by round piles. *If the piles are truly driven* a tight joint is generally secured by the swelling of the wood from moisture.

Fig 87.



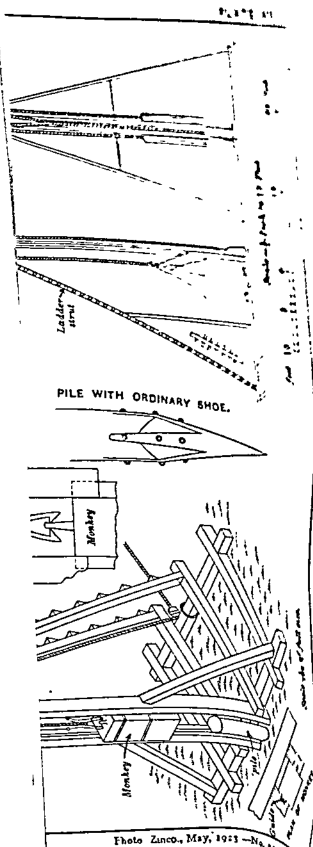


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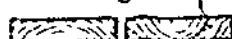


Fig. 84.

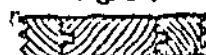


Fig. 85.

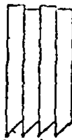


Fig. 86.



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pieces which are supported by round
a tight joint is generally secured by the swelling of the wood from moisture.

Fig. 87.



83. Numerous types of steel sheet piles are on the market; the best kind consist of special rolled sections which do not require any rivetting.



To protect the heads of the piles, especially sheet piles, from injury, a separate piece of wood called a *dolly* is generally placed on top which receives the blow of the ram and transmits it to the pile.

Interlocking steel and reinforced concrete piles have now quite ousted the use of cast iron or iron screw piles.

Sand piles are formed by driving ordinary wooden piles in firm ground, removing them and then quickly filling in with sand in thin layers which are carefully rammed. If the ground gives sufficient lateral support the piles will have a greater bearing power than the original piles.

84. A pile driver, or pile engine, consists of two vertical or inclined uprights firmly connected at the top by a cross-piece, and suitably strutted or tied. A ram, known as a *monkey*, is lifted by a crab or hoisting engine or by hand and allowed to suddenly drop on the top of a pile. When rising or falling it works in groves of the uprights which are called guides. When hand-power is used the driver is commonly called a *ringing engine*, and then only a light monkey is used. Several men raise the monkey with short sharp pulls and allow it drop on the pile, giving a light but rapid succession of blows. Types of pile-drivers are shown in plate VII.

85. Supporting power of piles.—Piles are generally of uniform section, but where the section varies the larger section should always be on top and the small section lowest down, as this method gives vertical support along the sides in addition to the increased friction. A pile driven with the large end at the bottom would also be extremely difficult to drive.

The Wellington formula for the safe load on a pile is—

$$P = \frac{2 W h}{S + 1}$$

When P = safe load in tons on pile,
W = weight of monkey in tons,
h = height of free fall of monkey in feet,
S = penetration of pile at last blow in inches.

Major Saunders' formula is:—

$$P = \frac{12\,W\,h}{8 \times S} \quad \text{or} \quad \frac{1{\cdot}5\,W\,h}{S}$$

This gives a factor of safety of ⅛th of the ultimate resistance.

A pile is ordinarily driven till the penetration at the last blow is less than ⅛″, but care must be taken not to over-drive and injure the pile.

86. In place of a series of piles to support the superstructure, it is customary in India to sink, by various processes, a well, or a series of wells and in Europe metal shells or tubes, which are filled with masonry or concrete.

These shells are generally circular in shape, and the necessary width or length of the foundation is then formed by a series of these shells, which are firmly joined together near the top, and form the requisite base for the superstructure.

Metal cylinders are sometimes sunk by divers or by the use of compressed air, and are then called pneumatic cylinders or tubes. Sinking is carried out by (1) weighting the wells or tubes with steel rails or other weights and excavating or dredging inside, or (2) for great depths under water, excavation in a working chamber under compressed air; this is called the pneumatic process and the cylinder a pneumatic *caisson*. The pneumatic caisson is really an inverted, air tight, open metal chamber which forms the working chamber, and is fitted with air—shafts, air locks, air-compressors, and lifts or pumps for removing the sand or mud. These are seldom used in India, and if used they would only be used for large bridges and need no further description here.

37. Well foundations.—*Well or block foundations* have been in use for very many years in India, and they are peculiarly adapted to the deep sandy beds of Indian rivers, and are extensively used both for bridges and buildings. A foundation may consist of a number of wells sunk close together and connected together afterwards, or of a block or blocks, which are square or rectangular, or other shaped wells of masonry made to the required shape; the latter, however, require experienced workmen, and circular wells are therefore generally used. In both cases the method employed is the same. An open excavation, larger than the well, is made till the soil becomes too moist to stand. At this level a wooden curb of durable wood (which is sometimes shod with iron), and of a thickness

PLATE VIII

Photo 7

varying from 6 to 18 inches, is made of the size of the well or block, and in breadth of the thickness of the well masonry. On this the masonry well is built up till it is about four feet above the ground, the sand inside is then scooped out, so that the curb and masonry descend. The curb is fastened to the masonry by long tie-bars built in as the well is constructed. Another four feet of the well is then built, and again the same process is resorted to, and the well again made to descend until any required depth is attained.

Great care has to be taken that the sand is scooped out gradually and evenly all round, so that the masonry may descend straight and not crack in its descent. The masonry must be properly bonded, as has been described in previous chapters, and made of the best materials. In important works hoop-iron and vertical iron rods in the masonry are used to give additional strength.

88. The wells or blocks are either driven down to the solid soil, clay or *kankar* or rock, or they may be suspended, as it were, in the sand by mere friction, the force of which is very great. If this latter plan be resorted to, however, the depths of the wells must be considerable, as when the river is in flood the sand may be scoured out for a considerable depth, the well then be deprived of its support for this portion of its length.

In Madras, when the wells are used to carry bridge piers, it is usual to only sink them for a short depth in the sand, the piers being connected together both at their up-and-down-stream ends by a line of wells acting as curtain walls, to prevent scour under the flooring of masonry or concrete which is made between the piers. A talus of loose stone is also added on the downstream side beyond the lower curtain walls as a further protection against scour. This arrangement may be a trifle cheaper, but is not recommended for general use. When the wells are finished, they are filled in with bricks or *kankar*, arched over, and connected together by arches, on the top of which the superstructure is built, or they may be filled with concrete from the bottom, thus forming a series of solid cylinders.

In all cases where the area of the foundation is composed of several or many continuous wells, it is advisable to sink them all together, as it is difficult to sink a fresh well close to one already down.

89. Excavating apparatus.—As long as the water in the interior can be kept out by pumping or lifting, the work of sinking the wells proceeds quickly, but when the work has to proceed under water, it is

very slow, and many different methods have been adopted to clear out the water and the earthen core of the wells.

90. The jham.—The simplest, and indeed the original Indian plan, is the use of a tool called a *jham*, which is a huge *phaora* or hoe, with a straight socket to it, in which a pole is fitted, and by which the *jham*, when lowered into the water, is kept upright with its edge downwards. The *jham* can then be worked into the sand from a staging above by pushing with the pole or by blows of a heavier pole guided by the diver on to the head of the straight socket. The pole is then withdrawn and by means of a windlass and a rope, which is attached to the inclined handle in front or centre of the *jham*, and so tips it horizonal when pulled on, the *jham* with its load of sand is dragged up and emptied. In some parts of the country the well-sinkers dive every time and work the *jham* into the sand by their hands, and divers have generally to be employed in case of any obstruction to the regular descent of the well. (*Vide* Plate VIII.)

A useful form of *jham* is shown in Figs. 89 and 90.

The *jham* is made of wrought-iron with a scoop two feet two inches wide and two feet four inches long, made thin and sharp at the front edge and supported by two stays fixed to the sides of the scoop, and also made thin and sharp at their front edges for penetrating the ground readily, the whole weighing about ¾ cwt.

Fig. 89.
Vertical Section.

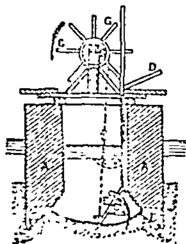
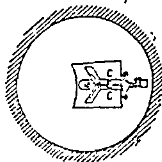
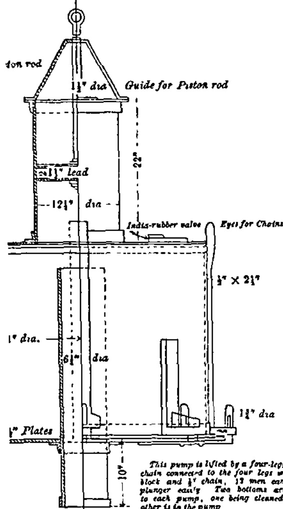


Fig. 90.
Plan of scoop

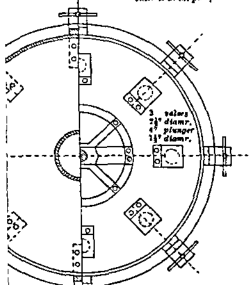


SAND PUMP.

the Beas Bridge Works—Delhi Railway.



This pump is lifted by a four-legged ¾" sling chain connected to the four legs with a single block and ½" chain. 12 men can work the plunger easily. Two bottoms are supplied to each pump, one being cleaned while the other is in the pump.



very slow, and many different methods have been adopted to clear out the water and the earthen core of the wells.

90. The jham.—The simplest, and indeed the original Indian plan, is the use of a tool called a *jham*, which is a huge *phaora* or hoe, with a straight socket to it, in which a pole is fitted, and by which the *jham*, when lowered into the water, is kept upright with its edge downwards. The *jham* can then be worked into the sand from a staging above by pushing with the pole or by blows of a heavier pole guided by the diver on to the head of the straight socket. The pole is then withdrawn and by means of a windlass and a rope, which is attached to the inclined handle in front or centre of the *jham*, and so tips it horizonal when pulled on, the *jham* with its load of sand is dragged up and emptied. In some parts of the country the well-sinkers dive every time and work the *jham* into the sand by their hands, and divers have generally to be employed in case of any obstruction to the regular descent of the well. (*Vide* Plate VIII.)

A useful form of *jham* is shown in Figs. 89 and 90.

The *jham* is made of wrought-iron with a scoop two feet two inches wide and two feet four inches long, made thin and sharp at the front edge and supported by two stays fixed to the sides of the scoop, and also made thin and sharp at their front edges for penetrating the ground readily, the whole weighing about ¾ cwt.

Fig. 89.
Vertical Section.

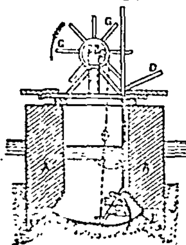
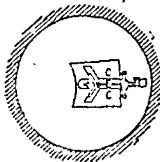


Fig. 90.
Plan of scoop



anything hard is met with, the pump can be lifted about four feet, and jumped up and down until the cutters have broken it. When once fixed in the sand, the piston of the pump is worked up and down by means of a rope and pulley, causing a current of sand and water into the cylinder, of which the sand settles into the cylinder and the water passes out through the top valves, until the resistance shows that the larger cylinder is full, or nearly so, of sand, when the whole machine itself is raised to the surface. Then one of the trollies, which work on a tramway, being run over the centre of the pier, receives the pump. The pins being then knocked out, and the legs turned round, the body of the pump is lifted, and the bottom is left on the trolly with its load of sand. The trolly is then pushed away, another run under with a spare bottom, which is fitted and the pump descends while the first bottom is being cleared out.

The pumps can be lowered and raised either by a gang of men working by an ordinary pulley and chain, or, what is better, by a steam hoist.

The work done by means of these sand pumps is very greatly in excess of what can be done by the ordinary *jham*, especially when the depth of water is great. They will also lift bricks and stones if not too large for the suction pipe.

92. Bull's Dredger.—(*Vide* Plate X.) A short chain four feet long, with a ring in the centre, should be attached by its ends to the rings on the chains working the machine. To the centre ring the chain for lowering and raising the machine is to be fixed, of a length greater or less according to the depth of the well. On the well two *ballis* should be fixed, with an iron block made fast to the junction. The *ballis* should not be less than 10 or 12 feet in length, stayed on either side to the ground. A wooden platform, 6 feet × 4 feet, composed of stout planks made fast to two under cross-pieces is also required, and two ¾ inch ropes, one made fast to the key keeping the jaws of the machine open and the other to the centre ring *in the short chain first mentioned.*

In working, the machine is opened on the wooden platform and the key fixed. It is then lowered into the well, and on reaching the bottom the key is withdrawn; the rope attached to the latter should be coiled on one side of the platform ready for use. A *gentle pulling-and-giving motion* should now be applied with the rope attached to the centre ring of the short chain, *slowly at first*, and *as this peculiar motion causes the jaw of the machine to sink or cut into the sand, the strain should be increased*, till there is no further yielding to the pull

which two men can put on the rope. The machine should then be raised and landed on the wooden platform. The operation of re-setting it, for lowering, releases the sub-soil brought up, and saves all trouble in emptying.

The average quantity brought up, when the machine is properly worked is two cubic feet: and in a well of 12 feet 6 inches in diameter, 38 feet deep, there is no difficulty in working it 25 times in an hour.

Three men on the top of the well (not including those employed in removing the sand, which is best done by contract) and 15 men to pull are required to work the hand dredger. The average performance per day in a 12 feet 6 inches well is three feet of sinkage for regular work; and, practically speaking, the depth of the well is of no consequence, the difference of time taken by the coolies walking 10 or 50 feet being inappreciable as compared with the time taken by each operation.

The dredger is principally intended for working in sand, but brings up anything which is cut up so that it can grip it. The motion of the wells being constant, they should not require weighting; and up to 35 feet it is seldom necessary to weight the wells.

This dredger is used extensively on the large bridges throughout India in preference to any other form of excavator. It can be made of very small width, for use in long slits in narrow curtain wall blocks which will not admit a man.

93. Strong and expensive well curbs are needed for heavy blocks or wells in loose soil, but in many ordinary cases, where sinking is even and easy, curbs made of two thicknesses of ordinary plank are sufficient; 18-feet wells are easily sunk on such curbs. Well curbs have also been made with platforms of solid hill bamboos, laid close side by side, well lashed at the corners and with under-cleats of short lengths lashed on for strengthening. All crevices were stuffed with grass, and care taken that no bamboos projected beyond the masonry.

94. Foundations in water.—In laying foundations in water two difficulties have to be overcome, both of which require resource and great care on the part of the Engineer. The first difficulty is the preparation of the bed of the foundation; and the second is in securing the bed from the action of the water, to ensure the safety of the foundations. The last is sometimes the more difficult problem of the two, for a large volume of water when the velocity is great will gradually scour, not only every variety of loose soil, but also some varieties of rocks, such as

the softer varieties of sandstone, and the calcareous and argillaceous rocks, particularly when the stratification is thin or of a loose texture.

The only difficulty which exists in the preparation of a foundation bed in stagnant water is to exclude the water from the area on which the structure is to rest. If the depth of water is small, this is done by surrounding the area with an ordinary water-tight bank of clay, or of some other binding earth. It may be necessary to first remove the soft loose stratum on the bottom before the bank is commenced; the bank is then made by throwing in successive layers of earth or by constructing walls of bags filled with earth. When the bank is completed, the water is pumped out from the enclosed area, and the bed for the foundation is prepared as on dry land.

95. Coffer dam.—When the depth of stagnant water is great, and in running water of any depth, the ordinary earth bank is generally replaced by the coffer-dam, or big crates filled with boulders and staunched with clay on the upstream side.

A coffer-dam is an enclosure built around the proposed foundation with the object of excluding the water and slushy soils during the construction of the masonry works.

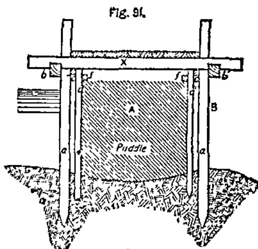
A coffer-dam is made of wood, metal or reinforced concrete piles and sheet piles, and placed in the form of a single or double shell crib. In single shells the joints are caulked, and in double shells the intervening space is filled with puddle to exclude the water.

The width of the casing between the sheeting piles should be so designed as to serve as a scaffolding for the machinery and materials required about the work. This is particularly necessary where the coffer-dam encloses an isolated position removed from the shore. The interior space enclosed by the coffer-dam should have the requisite capacity for receiving the bed of the foundations and such materials and machinery as may be required for the masonry construction.

The width or thickness of the coffer-dam, by which is understood the distance between the sheeting piles, should be sufficient not only to be impermeable to water, but to form by the weight of the puddling, in combination with the resistance of the timber work, a wall of sufficient strength to resist the horizontal pressure of the water on the exterior, when the interior space is pumped dry. The resistance offered by the weight of the puddling to the pressure of water can be easily calculated; that offered by the timber work will depend upon the manner in which

the framing is arranged, and the means taken to *stay* or buttress the dam from the enclosed space.

96. The usual construction of a coffer-dam is shown in the figure which is a section of one wall. It consists of a row of ordinary stout piles (*a*) round the area (*b*) to be enclosed, placed about four feet apart. A second row (*á*) is driven parallel to the first, the respective piles being the same distance apart; the distance *aá* between the centre lines of the two rows being so regulated as to leave the requisite thickness between the sheeting piles for the clay, etc., forming the dam. The piles of *each* row are connected by a horizontal beam of square timber, termed a *string* or *wale-piece bb'*, placed a foot or two above the highest water-line, and notched and bolted to each pile. The string piece (*b'*) of the inner row of piles is placed on the side next to the area enclosed, and those (*b*) of the outer row on the outside. Cross-beams *X* of square timber connect the string pieces of the two rows, upon which they are notched, serving both to prevent the rows of piles from spreading from the pressure that may be thrown on them, and as a joisting for the scaffolding. On the opposite sides of the rows, interior string pieces *cc* are placed, about the same level with the exterior, for the purpose of serving both as guides and supports for the sheeting piles. The sheeting piles *dd* being well jointed are driven in juxtaposition, and against the interior string pieces. A third course of string or *ribbon pieces ff* of smaller scantling confine the sheeting piles by means of large spikes against the interior string pieces.



As has been stated, the thickness of the dam and the dimensions of the timber of which the coffer work is made, will depend upon the pressure due to the head of water, when the interior space is pumped dry. For great depths, the Engineer must verify by calculation the equilibrium between the pressure and resistance.

In Figures 92 and 93 are shown cross-sections and the floor of a coffer-dam consisting of a single line of sheet piles, which is suitable

for sites where the soil is fairly stiff, or where difficulties in well-sinking are anticipated.

Fig 92, showing foundations built between a single casing coffer-dam.

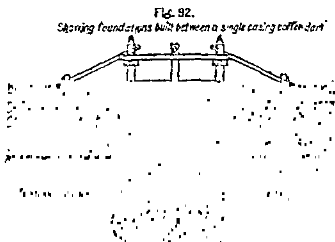
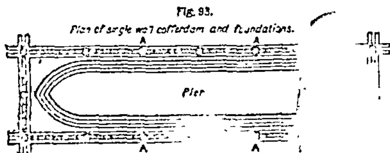


Fig. 93. Plan of single wall coffer-dam and foundations.



As the masonry rises, good ... will b... work, so as to completely fill the s... the ...

As there would be danger o... the piles, they should be cut off on com...

97. The main inconvenience ... difficulty of preventing leakage un... must be driven into a firm stratum, ... have a firm footing in a tenacious co... is necessary in the interior to unco... of the foundation is to be laid, the s...

least as deep as this point, and generally below it if the resistance offered to the driving does not prevent it.

The puddling should be formed of a mixture of clay and sand, as this mixture settles better than pure clay alone. Before placing the puddling, all the soft mud and loose soil between the sheeting piles should be carefully removed; the puddling should be placed and compressed in layers, care being taken to agitate the water as little as practicable.

With proper care, coffer-dams may be used for foundations in considerable depths of water, provided a water-tight bottom can be found for the puddle. Sandy bottoms offer the greatest difficulty in this respect, and in consequence masonry wells are generally used.

98. To give proper security to foundations in running water, the soil around the bed should be protected from the action of the current. The most ordinary method of effecting this is by throwing in loose masses of broken stone, block *kunkar* or concrete blocks, of sufficient size to resist the force of the current. This method will then give necessary security where the soil is not of a shifting character, like sand and gravel. To secure a soil of this last nature it may occasionally be necessary to scoop out the bottom around the bed to a depth of from three to four feet, and to fill this excavated part with concrete, the surface of which may be protected from the wear arising from the action of the pebbles carried over it by the current by covering it with cobble-stones.

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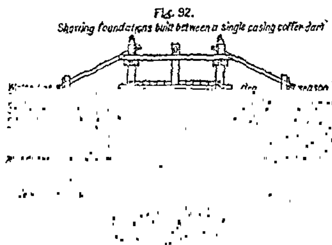
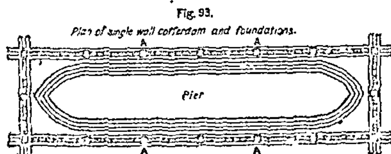


Fig. 93. Plan of single wall coffer-dam and foundations.



As the *masonry rises, good strong* clay will be rammed round the work, so as to completely fill the space between the dam and the pier.

As there would be danger of disturbing the bed by drawing the piles, they should be cut off on completion of the work *below the water-line.*

97. The main inconvenience met with in coffer-dams arises from the difficulty of preventing leakage under the dam. In all cases the piles must be driven into a firm stratum, and the sheeting piles should equally have a firm footing in a tenacious compact substratum. When excavation is necessary in the interior to uncover the sub-soil on which the bed of the foundation is to be laid, the sheeting piles should be driven at

least as deep as this point, and generally below it if the resistance offered to the driving does not prevent it.

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CHAPTER VII.

RETAINING WALLS.

99. Walls built of stone or brick masonry, concrete, ferro-concrete, or of a combination of any of these, for the purpose of holding up water, are called dams. But when such walls are built to support earth and to prevent it from sliding, they are called retaining or revetment walls.

Breast walls are a kind of revetment wall, erected to protect the exposed surfaces of cuttings from the deteriorating effects of the weather. Both retaining and breast walls are built either with or without mortar.

A combination of high-class masonry on the face of a wall with rubble or concrete at the back of the wall is suitable for all forms of retaining walls, because the pressure on the wall is concentrated towards the face, while the inferior kind of masonry in the backing gives stability by its weight. A wall built of two kinds of masonry must however be carefully bonded together with large headers. It is advisable to step out the foundation courses at the front of the wall in order to distribute the pressure over a greater area than that of any bed joint in the body of the wall, and distribute that pressure more equally by bringing the centre of pressure nearer the middle of the base than it is in the body of the wall.

100. The thrust of an earthen bank against a wall depends on a variety of conditions which it is very difficult to calculate accurately. When sand, gravel, and earths of different kinds are in a perfectly dry state, it is possible, by actual experiments, to calculate the thrust exerted by them. In practice however the soil may be found to be more or less saturated with water, and this would reduce the cohesion of the particles of the earth; while if the saturation were great, the earth would form into a semi-fluid, in which case its action would be more or less similar to that of a fluid.

The tendency of earth to slip will also very greatly depend on the manner in which the material is filled in behind the wall. If the ground is benched (*see* Fig. 94), and the earth is well rammed in layers which slope away from the wall, the pressure against the wall will be small,

assuming that proper attention has been paid to both surface and back drainage.

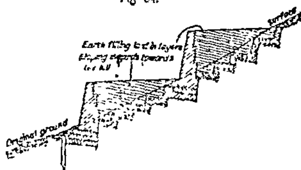


Fig 84.

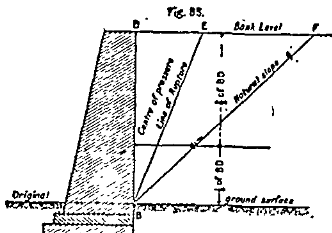
If, however, the earth is tipped carelessly, in the manner too frequently followed, or in layers slanting towards the wall, a greater pressure of the earth is exerted against the wall, and it must then be made of corresponding strength.

In ordinary cases the following is the rule:—The slope which the earth assumes, if left totally unsupported, is called the *natural slope* BF (*see* Fig. 95), and it has been found that the *line of rupture* (or that along which separation takes place in case of a *slip* of earth) generally divides the angle formed by the natural slope and the back of the wall, when vertical, into nearly equal parts (see BE).

The centre of pressure is that point in the back of the wall at which the horizontal thrust of the sliding mass acts, and this has been found by experiment and calculation to be at two-thirds of the vertical height of the wall from its top.

101. This wall may fail as a whole by *sliding* or overturning forward on its base, or by some portion of it sliding or over-turning on that below. In this last case the fore part or toe of the overturning portion may fail by crushing of the material. Taking the triangular section of earth DEB as sliding down BE, with or without friction, according to judgment, as the force tending to cause the wall to fail, and the weight of the wall as the resistance, the calculation is a simple mechanical problem easily solved graphically to give the direction and amount of the resultant thrust for the whole or any portion.

Fig. 83.



If this falls without the base the section will fail by overturning, and if it falls within the base (but too near the outer edge), the toe will be crushed. In either of the above cases, the section must be altered till the resultant falls far enough within the base. The pressure may be considered as distributed over the breadth between resultant and outer edge, *plus* twice this distance to the rear of the result.

The following are the natural slopes or angles of repose of various soils :—

Description of earth.	Angle of repose. From	To	Co-efficient of friction.	Customary designation of natural slope.
Dry sand, clay and mixed earth ..	37°	21°	0·75	1·33 to 1
			0 8	2·63 to 1
Damp clay	45°		1	1 to 1
Wet clay	17°	14°	0·31	3·23 to 1
			0·25	4 to 1
Shingle and gravel	48°	35°	1·11	0·9 to 1
			0·70	1·43 to 1

Rankine's formula is the one generally used for calculating the earth, pressure on the back of a wall; it must be noted however that it errs on the side of safety, because it takes no account of cohesion of the particles of the earth, and of the friction at the back of the wall. The formula is

$$\text{Horizontal resultant earth pressure} = \frac{Wh^2}{2}\,\frac{1-\sin\phi}{1+\sin\phi}$$

When W = weight of earth in lbs per cubic foot

ϕ = angle of repose of the earth

h = height of the wall in feet.

The following table shows the base to be given to triangular retaining walls of specific gravity equal to that of the earth sustained (supposed to be twice that of water) in terms of the height; the substance supported being supposed to be level with the top of the wall:—

	Nature of substance supported	Length of base in terms of height of wall; 135 lbs per cubic foot.
1.	Vegetable earth, carefully laid, course by course .. .	·185
2	Clay, well rammed	·195
3	Earth, mixed with large gravel	·250
4	Sand	·250
5	Sand, or mud, in a fluid state	·700
6	Water	·500

102. **Best form of retaining wall.**—At the top of a wall the pressure is *nil*. Going down from the top it increases as one descends till it is greatest at the bottom. Hence a gradual diminution of the thickness of a revetment wall towards the top is indicated, to prevent overturning by the action of a prism of earth at its back. This diminution in the thickness of a wall should be in direct proportion to the height, and the form of the wall should be that of a triangle. Against the pressure of a fluid tending to thrust the wall forward by destroying the cohesion of its joints, the diminution would be as the square of the height, which would give a concave batter in the form of a parabola for the outer surface of the wall. In practice, however, this is an expensive form, due to the extra labour required in building. For masonry intended for permanent exposures to destructive influences, the top of the wall should not be *brought to an edge, but must have a certain thickness, a frustrum of a* prism being the best practical form.

The following general rule is often adopted for practical purposes. Let the width of the wall at the base be as in the table above given, according to the nature of the substance to be supported; the thickness at top being about one-tenth of the height of the wall, up to 30 feet of wall, the minimum thickness under any circumstance being 1½ feet, the maximum *three feet, which need never be exceeded whilst the surface supported* is level with the top of the wall.

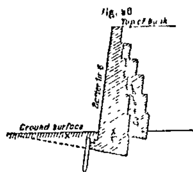
The front batter may be made to suit the circumstance of regard to convenience, appearance, etc. It may with [illegible] equal to half the difference in thickness between the bottom [illegible] wall; the front face of the wall should be smooth, but the rear be set off in equidistant steps at the back. The back [illegible] rough as the nature of the materials will admit of.

In a large structure, however, these empirical rules might add to its mass and to the expense of building with an actual diminution of strength: so that for these structures it will be necessary to calculate the correct form according to Moleworth's or Rankine's methods.

An excellent set of tables has been published by Mr. D. G. Harris, Executive Engineer, United Provinces, giving the base widths for different heights, batters, and top widths and for different natural slopes of the earth backing. These tables show the importance of giving a good front batter, and the very slight effect that an increase in the top width has in reducing the base width, and also the uselessness of a stability diagram for judging whether a design is economical or not.

103. Another point to be considered is, whether in addition to the weight of the ground behind the revetment, this ground be loaded by earth, buildings, etc., resting on it; if this additional weight is not thrown back beyond the line of rupture, allowance must be made for it by calculating the dimensions of a triangular revetment as for a height of earth equivalent to that weight, and then by cutting it down to the height to which the wall is to be built, so that it shall form a frustum of a prism whose thickness at the top will bear a due proportion to the thrust on the revetment on that line; of course the thrust will be modified by the breadth of the berm or distance to which the extra weight is thrown back.

104. Depth of foundations.—The friction between the wall and the ground will always be much less than the cohesion of the joints of masonry, for whilst the co-efficient of friction for stones and bricks in contact with each other is from ·65 to ·75, (irrespective of the cohesion of the mortar), it may, in wet clayey soils between masonry and slippery earth, be as low as 0·30. It is, therefore, requisite that the foundation should be of such depth that the passive resistance of the earth in front of it (marked x in figure) combined with the friction at the bottom, may counterbalance the active pressure of the earth on the back of the wall; and the greatest care is requisite to give revetment walls secure foundations, so as to prevent their either sinking or sliding forward; as if the earth supported by a revetment is once set in motion, the destruction of the revetment wall is certain.



Every course of a revetment wall should be built perpendicular to the outer face of the wall. This saves labour in cutting the face of the bricks or stones to a splay corresponding with the angle of the face line, and also increases the friction at the base and in every course.

The batter should be carried down to the bottom of the wall as this assists in keeping the revetment in place. In marshy or other compressible soil a footing of concrete should be provided and in some cases a row of piling with plank fender along the front or toe of the revetment to keep the foundation from slipping forwards. This expedient is however only recommended when more durable materials cannot be employed at a reasonable cost. The previous figure shows the best form of revetment, answering to No. 3 in the table with foundation, counterfort piling, etc.

The earth backing behind a revetment wall should be carefully laid in thin layers and should be well rammed ; it should also be laid continuously with the wall, but at a depth of about four feet below the top of the wall, as it advances This saves scaffolding and ensures the earth being thoroughly trodden down by the workmen employed on the building, and is not likely to cause an injurious pressure on the partially-set masonry.

When the material at the back of the wall is clean sand or gravel, so that water can pass through it readily, and escape by "weeping-holes" it is only necessary to ram it in layers. But if the material retains water, like clay, a *vertical layer* of stones or coarse gravel (at least a foot thick) or a dry stone rubble wall, must be placed at the back of the retaining wall, between the earth and the masonry, to act as a drain.

105. *Precautions against water.*—Water may almost always be prevented from getting to the back of a revetment, and this is a point that should be most carefully attended to ; but when there is a likelihood of water collecting behind a revetment wall, small drains called *weepers* should be made through the revetment, taking care to fill in behind them with pebbles or such other materials as will allow the water to pass through without bringing earth with it lest the drain itself should be blocked. *The weeping holes or* weepers are usually two or three inches broad, and of the depth of a course of masonry, and are distributed at regular distances, an ordinary proportion being one weeper to every four square yards of face of wall.

Along the base and in front of a retaining wall there should run a drain, like that at the foot of the slope of a cutting. A catchwater

drain also behind a retaining wall is often useful. It may either have an independent outfall, or may discharge its water through pipes into the drain in front of the base of the wall.

106. There are cases in which revetment walls, however massive, will give way, such as when a stratum of earth with an inclination towards the revetment is, by some change of its relations with the strata below it, set in motion. In such a case, instead of attempting to resist the motion by a thick retaining wall, the causes inducing it should be investigated and, if possible, removed.

Slips are often caused by draining off water from a saturated sand layer, or by allowing water to collect in sand which was previously dry. Clays of different composition lying on each other sometimes slip, from water penetrating between the strata; chemical changes sometimes take place from the exposure of certain soils to the air, causing motion and often occasioning slip. Retaining walls cannot be built to withstand thrusts of this nature, which must either be allowed to expend themselves, or a state of rest in the strata must be restored in some other way.

When material at the back of the wall is of a loamy description, and liable to be reduced to quicksand or mud by saturation with water, and there are no means of preventing such saturation by efficient drainage, one way of making provision to resist the additional pressure is by calculating the thickness of wall that would be needed if the earth were a fluid.

Another way of providing against such a contingency is to construct, sloping against the back of the wall, a bank of shivers of stone or coarse gravel, whose angle of repose is not affected by the presence of water, and then to fill in the softer material. The pressure against the wall in this case will not at any time greatly exceed that of a bank of the firm material employed, sloping at its own angle of repose.

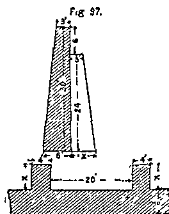
Another mode of relieving retaining walls from pressure is by the aid of arches, as described in paragraph 109.

107. Counterforts.—Retaining walls are often built with counterforts, or buttresses, at short distances apart. These allow of the average section of the wall being made less than would otherwise be the case, by enlarging the base of the structure in a greater proportion than its mass; care must be taken to thoroughly unite the brickwork or masonry of the revetment with that of the counterforts, or the former may be forced forward, leaving the counterforts behind.

Counterforts well united with a retaining wall are of the same advantage to it as cross walls in the superstructure of houses. Buttresses in front of a wall are more advantageously situated to prevent overturning than counterforts, but are of course inapplicable where a straightfaced wall is required. Counterforts too have the advantage of breaking up or dividing the pressure of the earth behind a revetment, and especially when this pressure is caused by the filtration of water.

The size of counterforts will depend on the height of the revetment; but about one-eighth of the calculated mass of masonry or brickwork may generally with advantage be thrown into this form; the distance of the counterforts from each other may range between the limits of 20 feet for high, to 10 feet for low, walls; they need not reach to the top of the revetment by double the thickness of the revetment at top (that portion being already stronger than is requisite for stability); their length at top may be equal to the top thickness of the revetment, and their breadth one-fifth of their distance apart. From these dimensions the length of the counterforts at the bottom can be found. Thin counterforts at frequent intervals will be more efficacious in breaking up the pressure to be sustained than thicker counterforts at longer intervals.

Fig 97.



Thus in a revetment 30 feet high, three feet thick at top, six feet thick at bottom, with counterforts 20 feet apart, the length of the counterforts at bottom, will be found easily, their breadth being four feet—

$$\frac{X+3}{2}(30-6)\times 4 = \frac{1}{8}\left\{\frac{6+3}{2}\times 30\times 24 + \frac{X+3}{2}(30-6)\times 4\right\}$$

which gives $x = 6{\cdot}64$ feet.

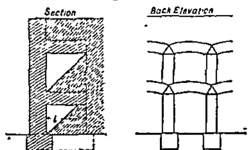
American Engineers consider that counterforts are a waste of money,

they believe that the masonry would be of greater value if it were given as extra footing in the foundations.

108. Hollow revetments.—In cases where the mass of brickwork required is sufficient to enable it to be divided into walls of not less than two feet in thickness, revetments may with advantage be built hollow, with partition walls taking the place of counterforts at intervals: in cases where an average thickness of more than four feet throughout is required, the front wall may be made thicker than the others with a batter, as in ordinary revetment walls.

109. Arches are turned on the counterforts, as piers, to carry the superincumbent filling, the counterforts being of such length that the *earth scarcely comes into contact with the back of the wall.* The wall is thus a mere shell blocking up the faces of the archways.

Fig 98



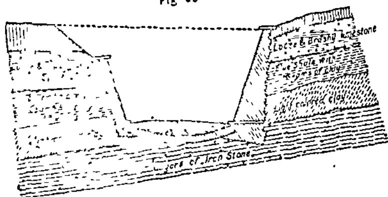
The arches may be in one or more tiers, and their length should be such that the line of the natural slope of the earth, touching their intrados at the crown should not cut the line of the back of the wall above the crown of the extrados of the next tier (*vide* section).

110. Breast walls—These are used rather to protect the surface of the cutting from the weather, and thus keep it from falling by disintegration, than to support any part of the mass behind it. Most soils will stand at a much steeper slope when first cut than afterwards; in these cases a mere facing of masonry will often be sufficient, care being taken to build it as soon as possible after the cutting has been made (before the surface has suffered from exposure) and not to leave the slightest interstice behind the wall; such interstices if they exist, should be filled in with small gravel carefully rammed, or with clay puddle.

Sloping revetments of even thickness not exceeding two feet are often used in such cases; and when the slope is very great and approaches

the permanent angle of repose, planting grass, sodding or covering the slope with rough flat stones prevents disintegration of the surface.

Fig 99



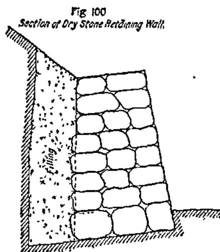
In cutting through strata which dip considerably, it will often be necessary to have a strong revetment on one side, whilst a thin facing will be sufficient on the other, as shown in the above figure.

As the permanency of breast walls is entirely dependent on motion not taking place in the mass behind them, special care must be taken to prevent the access of water to the back of such walls.

111. Dry stone retaining walls are built in a similar manner to coursed rubble masonry walls with the exception that mortar is omitted from them. A dry stone coping composed of stones laid on edge, is generally added at the top of the wall. Retaining walls require great care in their construction, as their stability entirely depends on the accuracy with which the stones are laid, and on the correctness of the bond. Unless the workmen are carefully watched, they may make a good face, while the filling and the backing may be laid carelessly and with unsuitable material For such reasons it is a good plan to collect all the material required before the work commences, and not to allow the earth filling at the back to be put in till every few feet of the work have been passed.

The correct section of a retaining wall depends on the nature of the stone used, the nature of the soil to be held up, and the skill with which the work is carried out. Roughly speaking, however, it may be said that a dry stone retaining wall should not exceed 20' in height, the top width should be about 2', the face batter 1 in 3 or 1 in 4, and the back vertical. The whole work should be built from the outside face up to, or

a little over, the full width of the wall, according as the stones may work out, any small excess in any particular course being disregarded. (*See figure 100.*) The courses should be laid at right angles to the front batter.



When a wall has to be built to more than 20′ in height, it is advisable to build the lower portion with mortar. Sometimes the interstices are filled in with mud or *bajri,* and the face of the wall pointed with lime mortar to prevent the mud or *bajri* from being washed out. In such cases the stones should be laid touching each other, and only the interstices grouted. Numerous weep-holes should also be provided in the wall.

The Engineer must be careful to see that the weepers in mortar or clay masonry are built right through the wall. As weepers interfere with the bonding, the masons, if not looked after, will blind weepers two or three feet deep from the outside, and these cannot be rectified later on without pulling down the entire wall. A good precaution, therefore, in building such walls is to see that every weeper has a stick left in it of the full thickness of the wall. When the Engineer inspects the completed work, he pulls out the sticks and tests the lengths of the weep-holes.

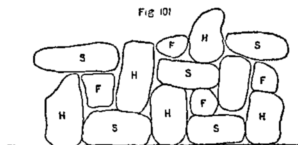
112. Dry stone walls in the Naini Tal District*.—"Two types of walls are used, *the first is known as the retaining wall section and has a top width of two feet, a face batter of 1 in 3, and a vertical back. The second type is known as a breast wall, and has a top width of two feet, a face batter of 1 in 2, and a back batter of 1 in 3.*"

* Details given by Mr. Oliff Lee, Assistant Engineer.

"No dry stone wall is made of a greater height than 10′, the portion of any wall below the level of 10 feet from the top is built in lime."

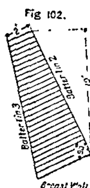
"The masonry in a dry stone wall consists of courses of roughly-dressed large stones laid as alternate headers and stretchers with filling pieces as shown in the sketch below. Headers are marked H, stretchers S, and filling pieces F."

Fig 101



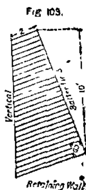
"All courses are laid with their plane at right angles to the face batter whether the case is abreast wall or retaining wall ; sketches of both are shown below."

Fig 102.



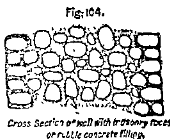
Breast Wall

Fig 103.



Retaining Wall

Fig. 104.


Cross Section of wall with masonry faces or rubble concrete filling.

"No course is allowed to consist of stones of a less thickness than 6″ and the largest stones are used in the lower courses. No stone in the wall may have a bed of less than 6″ × 9″ except the filling pieces previously described."

"All stones must be laid on their natural bed. The length of a header must always be a minimum of 4″ greater than the breadth of the stretchers on each side of it, so as to break joint by at least 4″."

"The masonry in the wall described above is locally known as '*pathao*' work, but, in order that the face of the wall shall be given a better finish, this face is specified to consist of a coursed rubble facing to a depth of 6" from the face. This merely means that the contractor is required to carefully hammer-dress all face stones to a depth of 6" from the face of the wall, so that no joint on the face shall be greater than ⅜"; joints up to ¾" thickness are allowed in the *pathao* work."

113. Masonry dams are fully described in the Irrigation section, so a lengthy description will not be given here. The great difference between revetment walls and masonry dams is that the former are designed for earth-pressures only, and any fluid pressure would be fatal to them, while the whole object of the masonry dam is to hold up water with the minimum of leakage, and it is designed accordingly.

114. Masonry dams are built of many types, but the gravity dam is the one generally adopted in India. Good formulae to determine the form to be given to masonry dams of gravity section can be found in books of reference, but Moleworth's formulae are generally used.

In masonry dams the conditions differ very little from those of earth retaining walls described in the preceding paragraph, except that the water-pressure always acts at right angles to the surface impinged on, and in Rankine's formula for the resultant pressure the angle (angle of repose) must be taken as zero.

High masonry dams are liable to crush in vertically from their great weight. It follows therefore that to add more material than is necessary is not to strengthen, but to weaken the work. As mortar may be assumed to be the weakest material in the structure, the calculations must be based on the strength or weakness of the mortar, and the pressure on a horizontal layer of the dam should never exceed the safe amount of compression to which the mortar may be subjected. Assuming then a practical width for the top of the dam, and proceeding downwards, immediately that layer is reached where the pressure approaches the safe amount (say 80 lbs. on the square inch) the width of the layer must be increased, so that no portion of the masonry wall shall be called upon to resist more than the allotted amount of compression. Such a dam, moreover, is subject to two different sets of conditions: *viz.*, (1) when the reservoir is empty, and the pressure on the inner face becomes most intense; and (2) when it is full, and from the thrust of the impounded water the pressures on the outward face are most intense. When flood-

water is passed over a weir, the levels of the flood above and below the weir should be calculated, and the stability of the weir tested, as this sometimes gives a worse condition than when the reservoir above the weir is full, and there is no water on the downstream side.

In a weir where flood-water falls on the face of the work, it is most important that the face should be smooth, and that the face stones are of proper size and thoroughly bedded in mortar, otherwise the force of the falling water will lever out or loosen the stones, or get behind the stones and force them out.

CHAPTER VIII.

CONCRETE.

115. Concrete is composed of "matrix" or mortar (possessing chemical binding properties) and an aggregate of hard material such as broken stone of varying size, gravel, or brick ballast. The matrix and aggregate are thoroughly mixed so that the voids in the latter are completely filled with the binding material. The latter is then wetted to set up chemical action causing the binding properties of the matrix to be exerted. Such a mixture when set forms a compact mass, but is only able to withstand compression stresses. When the concrete is required to withstand tensile stresses steel bars are added, and the mass is called "*reinforced concrete*." When large stones are placed in a concrete mass the structure is known as *rubble or plum concrete*.

The strength and other qualities of concrete depend mainly on the "matrix" or mortar which is used in its composition, but it also depends on the size, hardness, and quality of the aggregate, and on the method by which the concrete is laid. These points are described later on.

116. Plain concrete is very largely used for the footings of all kinds of work, and it is also sometimes used in their superstructure and frequently for floors and pavements of building and for the haunch filling of arches.

Reiforced concrete is used for practically every kind of work in buildings, bridges, and arches, etc. It is also used for such works as piles, pipes, columns, cisterns, dams, posts, tanks, etc. So far its use has been restricted in India on account of the high cost of Portland cement and the wooden formes, and also by reason of the difficulty of supervision; but in spite of this it is frequently more economical to adopt this method of construction than to build ordinary masonry, and its use is increasing rapidly every year.

117. The "matrix" or mortar used in concrete consists of a mixture of clean sharp sand with varying proportion of white lime, *kankar* lime, or Portland cement. In the case of white lime concrete "*surkhi*" is frequently added to give additional hydraulic qualities to the concrete. Concrete is sometimes called after the kind of lime which is used; for instance, it may be termed cement concrete, or *kankar* lime concrete. Reinforcement is seldom used with concrete made with white lime or *kankar* lime, as such concrete is seldom sufficiently impervious to protect

the steel from eventual corrosion. It has however been used with success in thick beds of *kankar* lime concrete footings where the foundation strata were uncertain.

White lime concrete, on account of its non-hydraulic qualities, is seldom suitable for foundation works, and should only be used for such works as spandrel-filling. The addition of *surkhi* (a chemically semi-action ingredient) has been found to give a measure of hydraulic property to white lime concrete.

The mortar receives less assistance in concrete, from the form and arrangement of the bodies it binds together, than it does in masonry work. It is therefore necessary that the mortar should be of the best quality which is available.

118. The lime or cement and sand are thoroughly mixed when dry according to the specified proportions on a wooden or brick or stone platform, water is then added gradually in sufficient quantity to form a paste which can be easily worked up. The mixture is then carefully kneaded and mixed in the correct proportions with the aggregate ; *kankar* lime mortar which is mixed in a wet state by machinery or in a bullock *chakki* is far superior to that mixed by hand. Wet grinding is generally insisted on for masonry work but seldom for concrete though it is of equal importance when good work is required.

The following mixtures of mortar have been found to yield good results in practice :—

	Kankar lime	*Surkhi*	Sand
	1½	½	1
	White lime	Sand	*Surkhi*
(*a*)	1½	1	½
(*b*)	2	1	1
(*c*)	2	..	1

When mortar is not ground wet and when the lime and ballast are not machine-mixed, the ballast is stacked to an even and convenient height on a temporary platform. The correct proportion of the lime and sand mixture is then placed evenly over the ballast, and the ingredients are first mixed dry. Water is then added gradually and the mixing is continued by turning over the mass with *phaorahs* till the mass is thoroughly mixed and of the correct consistency. A good test of mixing is the degree to which every piece of aggregate is covered with mortar.

The thorough mixture of the mortar and the aggregate is of the greatest importance ; hand-mixing when properly done is excellent, but machine-mixing is better because it gives more consistent results.

concrete work. A dry mixture enables much longer and more severe ramming to be done before the lime flushes to the surface, and the mass is therefore generally more compact. On the other hand, a wet mixture enables the concrete to be placed more evenly, and it ensures all hollows being filled up, but it cannot be rammed, for if it were the lime would flush immediately to the surface. The mortar in drying must leave small hollows, so the concrete is liable to be spongy.

In wet concrete "laitance" or the accumulation of overhydraulic cement flour is liable to occur at the planes of junction between the layers. These can be detected in any exposed section of concrete and are sources of great danger in dams and other structures subject to pressure.

The best mixture is probably the one which has enough water to enable the concrete to be efficiently worked and pushed into hollows, but not so much water as to prevent a fair amount of ramming or to cause spongy layers between the "works and planes." Such a mixture can easily be worked into all hollows; it is compact, because it can be properly rammed, and is not spongy because there is not an excess of moisture.

A drier mixture can be used for large blocks or thick slabs of concrete than it is possible to use for reinforced or plum concrete.

Contractors unless watched are apt to lay a thick layer, with a sloppy mixture, and then ram it too much. In such cases the top of the layer has an excess of mortar while the bottom of the layer will be full of voids.

It has been observed in laying cement reinforced concrete, that the labour charges are halved by using a wet concrete. Excessively wet concrete causing bulging of the frames and forms when laying reinforced concrete, and expensive stages are necessary to keep the form in alignment.

The amount of mixture at the mixing floors will of course vary with the temperature of the days, the lead to the work, and the nature of the members to be converted, but care is to be taken that, as noted above, excessively wet concrete is not laid in the work.

124. Ramming has no effect at the bottom of a thick layer made from an ordinary mixture, layers about 6" thick are therefore recommended for all important works. In reinforced concrete work and in plum concrete it is advisable to lay the mixture carefully between the steel bars or stones for a small depth such as 6", then to level it off and push the concrete into all hollows and finally to ram gently for a few minutes only. With quick setting cements a minimum of ramming should be done.

When concreting curved girders or arch ribs it is advisable to tamp

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118. The lime or cement and sand are thoroughly mixed when dry according to the specified proportions on a wooden or brick or stone platform, water is then added gradually in sufficient quantity to form a paste which can be easily worked up. The mixture is then carefully kneaded and mixed in the correct proportions with the aggregate; *kankar* lime mortar which is mixed in a wet state by machinery or in a bullock *chakki* is far superior to that mixed by hand. Wet grinding is generally insisted on for masonry work but seldom for concrete though it is of equal importance when good work is required.

The following mixtures of mortar have been found to yield good results in practice :—

	Kankar lime	*Surkhi*	Sand
	$1\frac{1}{2}$	$\frac{1}{2}$	1
	White lime	Sand	*Surkhi*
(a)	$1\frac{1}{2}$	1	$\frac{1}{2}$
(b)	2	1	1
(c)	2	..	1

When mortar is not ground wet and when the lime and ballast are not machine-mixed, the ballast is stacked to an even and convenient height on a temporary platform. The correct proportion of the lime and sand mixture is then placed evenly over the ballast, and the ingredients are first mixed dry. Water is then added gradually and the mixing is continued by turning over the mass with *phaorahs* till the mass is thoroughly mixed and of the correct consistency. A good test of mixing is the degree to which every piece of aggregate is covered with mortar.

The thorough mixture of the mortar and the aggregate is of the greatest importance; hand-mixing when properly done is excellent, but machine-mixing is better because it gives more consistent results.

119. The aggregate, or ballast, as it is generally called in India, is made from any hard stone, gravel or brick and broken to small pieces. Slag and coal cinders are also used in places, but are unsuitable for good work as they frequently contain some chemical impurities which will deteriorate the concrete. Quartz and flints are unsuitable for concrete work because their surfaces are smooth and the matrix is unable to grip them. Ballast for ordinary work is generally broken so that no dimension of any piece exceeds 1½ inches. A better concrete is made with one inch ballast, but this costs more and its use is only justified in important works. The advantage of small ballast is that only hard stone can be broken to this size, less mortar is required to form a solid mass, and there is far less chance of cavities in the completed work. When stone-breakers are used it is impossible to specify more than a limited percentage of small ballast, such as three-fourths or one inch, as these machines cannot break it small without powdering up most of the stone.

For reinforced concrete good gravel is generally used in preference *to broken stone or any other material. The disadvantage of gravel is* that the surface is inclined to be smooth or rounded, both of which conditions should be avoided where possible. The smallest particles must not pass through a ¼ inch mesh, and the largest particles must be less than the clearance between the reinforcement and the centre or between the bars which form the reinforcement. ¾ inch is a suitable size for beams, and ½ inch for slabs and thin walls.

An ideal form of aggregate for reinforced concrete is what is known as "graded aggregate." 60 per cent. of say ¾" gravel would be mixed with 30 per cent. of ½" gravel, with 10 per cent. of ¼" gravel. The voids in the aggregate are thereby reduced to a minimum.

120. Sand.—The importance of procuring pure sand for concrete work cannot be too strongly emphasised. Coarse, sharp new sand should be got at any cost. Concrete made from fine sand however pure, is rarely sound in practice.

Screenings from broken ballast down to a minimum size of ⅛" × ⅛" and up to a maximum of ¼" × ¼" can be classed as sand conveniently, if natural sand cannot be got.

The sand should be washed in running water if possible and a good test is to take a handful and hold it in clear water, and note whether there is a cloudy residue or not.

121. The proportion of lime or cement, sand and ballast used in

concrete work varies with the kind of work and with the nature of the sand and ballast. In making mortar the lime or cement is mixed with the sand and the flour-like particles of the lime or cement fit in between the grains of sand occupying a part or all of the voids.

In the same manner the mortar, which is composed of the mixed lime and sand, mixes with the ballast and fills up the voids. The best proportions for the materials which compose the concrete are such as will fill all the voids properly, and this can only be determined by practical tests. First find the voids in the sand by filling up a vessel of known capacity with damp well-packed sand and adding water by measure till it overflows. In a similar manner the amount of water which is required to fill up the voids in the ballast can be tested by measure. Suitable proportions for the ingredients can then be calculated.

Experiments show that the voids in gravel vary from 30 to 45 per cent. and with broken stone the voids seldom exceed 50 per cent. The voids in damp, well packed sand are much less than in loose dry sand. Sand voids vary from 30 to 40 per cent.

A common proportion for cement concrete, either plain or reinforced, is what is known as the 1 : 2 : 4 mixture, namely 1 part cement to 2 parts of sand to 4 parts of ballast.

When concrete is made with white or *kankar* lime the proportions of the mortar are similar to those used in other kinds of masonry (*see* Appendix I). Fifty per cent. of mortar is generally used with stone ballast, and 33 per cent. with brick ballast.

122. Plain concrete should be laid in horizontal* layers from 6" to 12" thick and the surface should be levelled with the trowel or *phaorah* and then steadily rammed till the lime flushes on the surface.

To make a good joint between any two layers, the upper layer should be laid before the lower has set. When the lower layer has set, the top surface should be cleaned, roughened with a pickaxe, and damped before the next layer is laid. It is also generally advisable to lay a little plain mortar over the old layer in the form of plaster to ensure a good joint between the two layers. Before plastering the layer it is advisable to scrub it with a stiff wire brush.

123. Opinions vary greatly regarding the amount of ramming that should be done, and as regards the proper consistency of the mixture for

*In the case of concrete subject to oblique pressure, *e.g.*, in the hearting of a dam near the downstream toe, it is sometimes advisable to lay the concrete in sloping layers at right angles to the direction of thrust.

concrete work. A dry mixture enables much longer and more severe ramming to be done before the lime flushes to the surface, and the mass is therefore generally more compact. On the other hand, a wet mixture enables the concrete to be placed more evenly, and it ensures all hollows being filled up, but it cannot be rammed, for if it were the lime would flush immediately to the surface. The mortar in drying must leave small hollows, so the concrete is liable to be spongy.

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124. Ramming has no effect at the bottom of a thick layer made from an ordinary mixture, layers about 6" thick are therefore recommended for all important works. In reinforced concrete work and in plum concrete it is advisable to lay the mixture carefully between the steel bars or stones for a small depth such as 6", then to level it off and push the concrete into all hollows and finally to ram gently for a few minutes only. With quick setting cements a minimum of ramming should be done.

When concreting curved girders or arch ribs it is advisable to tamp

the concrete roughly tangentially, *i.e.*, on radial working planes, so that the consolidation shall follow the direction of ultimate pressure.

Concrete should not be thrown on the site from a height, or run down a shoot, as in such cases the heavier stones go first while the mortar remains behind and the result is an imperfectly mixed mass

125. Completed concrete should measure a trifle more than the ballast measurement because the mortar is generally specified a little in excess of the actual voids to be filled. For instance it has been found that 100 cubic feet of gravel (aggregate) *plus* 50 cubic feet of sand and '25 feet of cement yield 100 to 125 cubic feet of finished concrete as measured in the work—an increase of 20—25 per cent. over the amount of gravel used. It is advisable therefore to pay the contractor on mixing floor measurements or to "correct" the rate for measurements taken of finished work.

126. Rubble or plum concrete is cheaper than stone masonry and is very useful for the interior of thick walls, or for large spandrel fillings. It is also easier to build than ordinary masonry, as it merely requires only one experienced man to supervise, and he does not need the assistance of any masons; labourers also quickly learn the proper methods of carrying on the work. When plum concrete is used for the filling of thick walls, the outer and inner faces are first built with stone masonry for a convenient height, such as two feet, and then the central space is filled in with plum concrete. Before the filling in is commenced the completed work should be cleaned (preferably with wire brushes) roughened and thoroughly wetted. If the old work has "set" it is necessary to spread a coat of mortar-like plaster before the new concrete is laid. A few inches in thickness of concrete are then laid, and on this stones of any convenient size are carefully bedded. These stones should be laid as irregularly as possible, so as to cut joint both horizonally and vertically. These spaces between the stones are then carefully filled with plain concrete in thin layers, and thoroughly worked into all hollows and openings; the concrete is then gently rammed and another layer laid. Contractors like to fill in the spaces between the stones in one thick layer, but when this is done, it will be found impossible to fill in the hollows properly.

The lateral intervals between stones cannot be exactly specified, but should be sufficiently large to permit of thorough working and ramming of the concrete. Contractors naturally prefer to overstock the concrete with plums, and it is advisable to lay down a maximum percentage of "plums" for any particular work in the specification.

128. For walls, arches, etc., for which cement concrete or reinforced concrete is used, it is customary to construct wooden or metal formes or frames which will retain the concrete in the required shape. Metal is seldom used except in formes for pipes and ties for wooden frames.

The materials used in formes and staging are expensive, the cost of erection and removal is also considerable, consequently the greatest care should be given to the design and construction.

Slight alterations in the design of the concrete may enable the formes to be used over and over again for different parts of the work, and this means a great saving in cost.

In the actual erection of the formes endeavours should be made to use sizes of planks and other scantlings which require a minimum of cutting and to use clamps and wedges, where possible, instead of nails. In re-erection workmen frequently cut up timber to save themselves the trouble of searching for the right piece, and this results in great waste. A large contractor's foreman said that to supervise this was his principal work, and if neglected there would be no profit from the contract.

In a manual of this size it is impossible to give details of the formes and staging which have been used with success in the different kinds of work for which concrete is suitable, but the following general details may be found useful:—

(1) Economy in timber.—The timbers used must be strong enough to stand without distortion; also that when removed, they should be suitable for re-erection Possibly thin sections of timber might serve the purpose for one work, but if they were unfit for further work it would generally be found to be more economical to use a thicker section.

(2) Economy in the carpenter's work.—Clamps and wedges should be substituted for nails, and extra work should be put into framing the formes to withstand the stress of repeated use. This will generally be found to be economical.

(3) Soft wood should be used, such as good chair or deodar, but mangoe may be used for ordinary works when other kinds are not available. The timber should be dressed, as it permits of tighter joints and gives a smooth surface finish to the concrete; it also simplifies the removal and cleaning of the formes. Undressed wood may be used for the backs of walls or work below ground level.

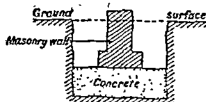
(4) Economy in taking down, removal, and re-erection.—The formes should be designed so as to come apart in units by removing bolts,

Stones must be laid so that there is always sufficient space on all sides to ram the plain concrete filling. They should also be laid with the thinnest side on top and the thickest at the bottom, unless this is done hollows cannot be filled and ramming is impossible.

It is also a good method to lay the stones in such a manner that when the filling between them is half done, there is sufficient space for another layer of stones to be commenced. This ensures the cutting of the joints in a vertical direction, but contractors avoid laying them in this way when possible, because it adds to the workmen's difficulties in carrying the stones and concrete. The face masonry should be bonded into the plum concrete by the use of irregular thickness of stones or courses. For instance, if the thickness of the front and back faces are entered as two feet thick in the drawings, the first course should be about 2′ 3″ thick and the next about 1′ 9″ thick and so on.

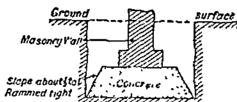
127. Concrete is a plastic material and consequently requires wooden formes or some other support to keep it in the required shape until it has hardened sufficiently to stand without assistance. For the thick foundation blocks of plain concrete it is usual in India to excavate to the required section and use the earth sides of the foundation pit to retain the concrete in the required shape (*see* Fig. 105). It is, however, impossible to ram the edges without displacing the earth and mixing the earth with the concrete; it is therefore much better to dispense with the earth moulds and lay the concrete as is shown in Fig. 106. This enables the sides to be rammed and the whole mass of the concrete to remain sound instead of the edges being spongy and week. It also gives a greater foundation base without increasing the quantity of concrete. When laying expensive kinds of concrete in open foundations, especially in unstable soils, where the excavation has to be carried well beyond the edge of the work, it is often advisable to lay the concrete in dry brick moulds.

Fig. 105.



Showing ordinary method of building concrete foundations

Fig. 106.



Showing correct method of building concrete foundations

128. For walls, arches, etc., for which cement concrete or reinforced concrete is used, it is customary to construct wooden or metal formes or frames which will retain the concrete in the required shape. Metal is seldom used except in formes for pipes and ties for wooden frames.

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(4) Economy in taking down, removal, and re-erection.—The formes should be designed so as to come apart in units by removing bolts,

clamps and wedges. The removal and re-erection can usually be done by labourers only with a carpenter to superintend. Battens of sal wood are economical to stiffen the forme planks at intervals, depending on the depth of the member. Angle irons are also useful. Planks should be dowelled together at the joints.

(5) All concrete formes require a coating of some lubricant to prevent the concrete from adhering to the wood with which it comes in contact. The use of a lubricant also gives a smoother surface to the concrete, and assists in saving the wood and reduces the cost of removing the formes. *Crude oil, soft soap or other greasy substances are used.*

(6) No hard and fast rule can be given for the time that staging should remain before removal. A great deal depends on the atmospheric conditions and on the nature and form of the concrete. Concrete walls usually require the formes to be retained for a few days only. For beams and girders and long span slaps two or three weeks are sufficient, while the staging for arches of large spans should not be removed for two or three months.

129. Concrete has frequently to be laid under water, and if there are any currents or waves, most of the mortar will be washed away, unless some special method of laying is adopted. Even in still water it is generally necessary to take special measures, lest the concrete be greatly weakened, the lime or cement floating up in suspension and forming a scum on the water.

The methods which are generally adopted in laying the concrete under water are :—

(1) By constructing temporary walls such as coffer-dams made with wooden sheet piles, and laying the concrete inside in the still water, or removing the water and laying the concrete in the usual manner in the dry. As the cost of the coffer-dam is considerable, this method should only be resorted to in important works, when other methods are impracticable.

(2) By conveying the concrete in steel boxes or bags and depositing it in the correct position.

Concrete is filled into specially prepared steel buckets or boxes which have a trap door at the bottom. The box is then raised by a crane and lowered through the water into the correct position. The trap door at the bottom is then opened and the concrete dumped.

Strong gunny bags are sometimes used to carry the concrete through the water, and tip it at the bottom. A much better method is, however,

to fill thin gunny bags with concrete and lower these through the water into their proper position. The bags quickly adjust themselves while the mortar oozes through them and forms a solid mass.

130. **Methods of water proofing concrete.**—Resistance to penetration by water is essential in structures such as tanks, reservoirs, roofs, floors of aqueducts, etc. Ordinary concrete is pervious to water. Many methods with more or less success have been tried for water-proofing it, but at present it cannot be said that any one of them is absolutely satisfactory. The methods for water-proofing are classified as follows :—

(1) The use of mixtures so proportioned as to be impervious.

(2) The admixture of substances designed to produce imperviability.

(3) The use of water-proof coatings, washes, or diaphrams.

(4) Plastering the inside of the tank with unhydrated lime mortar and then filling the tank. The walls are subjected to pressure whereby the white lime in solution is forced into the pores of the concrete, which are thus filled up by crystallisation, and cease to leak in the course of a few weeks.

In ordinary concrete the most impervious mixture will be given when there is an excess of cement and of mortar, when the sands consist of different size of grains (the proportion of medium size grains should be small, and the proportion of large and small size about equal), and when the mixture is sufficiently dry to be worked satisfactorily.

A small admixture of slaked lime, which has been worked into a milky condition, undoubtedly improves the water-tightness of both kankar and Portland cement concrete ; the best mixture greatly depends on the size and nature of the stone and sand, and should be decided after tests have been made ; it may vary from one-third to a quantity equal to the cement.

There are numerous patent water-proofing compounds on the market, the best known being the "Medusa" compound which is mixed with the concrete and gives good results. Concrete is made watertight and the strength also increased by using from 2 to 5 per cent. alum in the water, and also by adding from 5 to 10 per cent. finely-powdered clay.

Numerous washes have been tried with more or less success, but if there is any crack in the concrete their value is entirely lost. The Sylvester water-proofing process is as follows :—

"Dissolve ½ lb. soap in one gallon of water, and ½ lb. of alum in 4 gallons of water. Apply the soap wash at boiling heat with a brush on a dry surface, care being taken not to froth the soap. When the soap

diameter are generally used for the reinforcement in slabs, and 3/4" to 1½" diameter in beams. There are also many kinds of patent bars (some twisted and some indented) which are designed to increase the adhesion between the steel and the concrete. Their use is not recommended as there is a great difficulty in filling every crevice of the bar with concrete unless an objectionably wet concrete is used. If the calculated adhesion stress between the concrete and steel does not exceed 100 lbs. per square inch, there is no fear of failure occurring due to "slipping."

Bars must never be painted, oiled or rubbed to form a smooth shining surface, but all dirt, grease or rust scale should be removed before they are embedded in concrete. A thin rust film is not objectionable, because it increases the cohesion between the steel and the concrete.

The ends of bars are turned upwards to prevent sliding of the bar in the concrete. When one bar is not of sufficient length another bar is added and a lap of from 24 to 40 times the diameter, etc., of the bar is given. In slabs and beams the lower surface of concrete is laid and then the reinforcement bars are laid on top in the correct positions. If, however, there is any likelihood of there being a delay in the correct placing of these bars, it is best to place the steel bars in the correct position before concrete work is commenced. The steel bars are kept in correct position by spacing of pieces of wood at suitable distances, or in deep girders and ribs by supporting them on transverse bars through the framing. The concrete is laid all round the bars where there are no spacing blocks, and when the bars are properly held in position by the concrete the wooden blocks are removed.

Sharp corners should never be given to reinforced concrete work; they can easily be rounded off by wooden pieces cut to the right shape and fixed to the centres.

134. Preservation of concrete.—Protection of cement concrete against extremes of temperature for some time after laying is most necessary. Frost rarely occurs in India except on the frontier, but protection against heat is essential. The side formes retain moisture and protect the surface of the concrete, hence this is an argument against early removal of formes. The tops of ribs, girders and slabs should be covered over with wet sacking immediately after "initial set" of the concrete has occurred, and kept wet for at least seven days. It is advisable to flood the level surface of a finished work, *e.g.*, a floor or slab; concrete so treated has been found entirely free from expansion hair cracks.

CHAPTER IX.

POINTING AND PLASTER.

135. When a masonry work is completed, it should be pointed or plastered with Portland cement or with lime mortar. There are many ways of pointing and several kinds of plasters, and one or other is used in accordance with the conditions of the work, which will be described later on. Plastering consists in applying different compositions resembling mortar, in thin layers of one, two or three coats (as may be specified) to the external or internal surfaces of a work, in order to improve their appearance and protect them from the weathering effects of the atmosphere. "Plastering" is sometimes called "rendering." Technically speaking, "plastering" refers to the covering over of wooden *laths* or steel netting, while "rendering" refers to the coatings placed over masonry walls. In India the word "rendering" is seldom used, so in the following pages the term "plastering" will be used for both "rendering" and "plastering."

The interior of a building is generally plastered, but the exterior should never be plastered if the materials of which the work is composed are able to withstand the deteriorating effects of wet, heat, frost, smoke, etc., to which they may be subjected. Engineering works are nearly always pointed on the outside with specially prepared cement or lime mortar in order to give a neat finish, and also to protect the joints from the action of the weather and of water.

Before plastering or pointing is commenced, the masonry joints are thoroughly cleared out for a distance of from ½" to 1" from the face, according to the nature of the work, and then the whole of the face is thoroughly damped. If this damping is not fully carried out, the mortar of the plaster or pointing will rapidly suck up the moisture from the completed work, and will soon crack off. In large weirs the joints are cleaned out for a distance of 2" to 3" from the face.

All pointing work should be carried out as soon as possible after the masonry course is completed and before the mortar has properly set. If this is not done, a good contact will not be secured and the pointing or plaster will crack and fall off.

Some Engineers consider it is best to point with Portland cement after the masonry work built with lime mortar has set, their argument being

that, if the pointing is done before the lime mortar has set, cracking may result, as Portland cement dries more readily than lime mortar. This argument may seem sound, but experience has shown that better results are obtained when the pointing work is done quickly. The probable explanation of this is that the pointing in this case is kept more systematically and longer damped together with the masonry itself, when done immediately after the completion of the masonry work than when the pointing is done at a later date.

It is a good practice for the Engineer not to allow plastering or pointing to be commenced till the cleaning out of the joints has been examined and passed by a responsible man. Care should be taken that the completed pointing or plastering is kept damp for at least a fortnight, otherwise the work will assuredly crack and eventually fall off.

Specifications for pointing and plastering are given in Appendices X and XI.

136. Pointing.—The mortar which is used for pointing is specially prepared. For cement pointing a richer mixture of cement and sand is used than is customary for masonry work. A finer sand is also used. The usual proportions are 2 or 3 parts of sand to one of cement. A richer mixture than this is liable to crack.

For white lime pointing a pure lime is selected, and this is specially made into what is called lime putty. Hydraulic lime is ground very finely in hand mills and made into putty.

Flat or flush pointing.—The mortar is placed in the joint and pressed tightly and smoothed by a trowel till the surface is flush with the rest of the wall (*see* Fig. 108, Plate XI).

This is not an ornamental kind of pointing, but should always be used for dams, falls and other works which are subjected to the action of water. It is also used for all internal surfaces of buildings which are white-washed. For internal or rough work no new mortar is used, but the mortar forming the masonry joint is smoothed off flush with the trowel.

Flat jointed pointing.—This is prepared very similarly to flush pointing, and is often called *line pointing* in India (*see* Fig. 109 and 110, Plate XI). On the flush surface an iron rod called a jointer is pressed against the centre of the joints. This marks a narrow line which improves the appearance of the work, and has also the effect of making the mortar more dense.

OF DIFFERENT TYPES OF POINTING.

Fig 109.

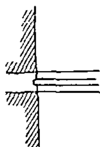
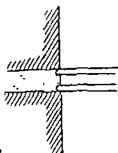
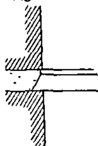


Fig. 110.



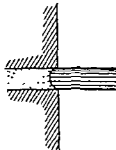
JOINTED OR
LINE POINTING

Fig. 112.



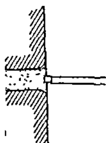
(*Bad form*)

Fig. 113.



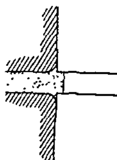
KEY POINTING

Fig 115



TUCK

Fig. 116.



BASTARD TUCK.

Photo. Zinco., May, 1913—No. 6593—10,2000.

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Struck pointing is made by pressing back the upper portion of a joint while the mortar is moist, the lower side of the joint being cut off by a trowel to a straight edge, (*see* Fig. 111, Plate XI).

This method of pointing makes an excellent joint, because the upper edge of the mortar is protected by the masonry and water runs off easily from the lower edge. The reverse is frequently done and the resulting point is then a bad one (*see* Fig. 112, Plate XI).

Keyed pointing.—The joint is first filled up flush and then a circular shaped piece of iron (called a jointer) of the same diameter as the thickness of the joint is drawn along the joint, pressing the mortar in beyond the face of the wall (*see* Fig. 113, Plate XI).

Masons or V pointing.—This is a common type for stone masonry, but it is liable to be broken off, as it projects from the face of the wall in an angular or V section (*see* Fig. 114, Plate XI).

Tuck pointing is generally used in brickwork to give a neat appearance to interior work, and is not recommended when the bricks or stones are sound and have sharp edges. The joint, after it has been raked out and cleaned, is filled up flush with mortar, and the surface is coloured with some colouring material or rubbed over with a soft brick, until the mortar of the joint and the bricks are of the same colour. A narrow groove is then made with a jointer along the centre of each joint, and the mortar allowed to set. The groove is then filled in with white lime putty and made to project slightly, the edges are cut off neatly, leaving a white band about ¼" or more in width (*see* Plate XI, Fig. 115). By this process false joints are struck and bad work is disguised; it is consequently not recommended for engineering works.

Bastard tuck pointing is very similar to tuck pointing, except that the ridge is wider and is made of the same mortar as the filling of the joint.

137. Varieties of plaster.—There are many varieties of plaster, those best known being called pukka and kacha plaster. Of pukka plaster again there are many kinds, named by the materials of which they are composed, such as cement plaster, kankar lime plaster, white lime plaster, etc.

In all hydraulic works cement or kankar lime should be used, but for buildings, especially the interior of buildings, white lime plaster is quite good enough. The methods of construction of all varieties are very

may be preserved from cracking. For plaster work on the Solani aqueduct, near Roorkee, the following proportions were used :—

3 parts kankar lime.
1 part white lime.

Water is added very gradually, and the mixture is then carefully stirred and worked up till a smooth appearance is produced.

If the walls to be covered are uneven, their irregularities should first be carefully filled in with concrete made of fine shingle or small pieces of hard bricks mixed up with the mortar mentioned above. When this has nearly set, a coating of plaster from ⅜" to ½" thick should be laid on and brought to a smooth and even surface with a long straight edge. It should be then well beaten with small pieces of wood or strips of bamboos. This patting should be continued day after day till the plaster coat hardens. If this is not done, the plaster will crack badly; but if the patting be continued after the plaster has hardened, it will cause injury to the work. The final coating consists of a mixture similar to the lower coating, but much more water should be added to it, and the ingredients should be strained through a coarse cloth to remove any coarse pieces of burnt kankar, etc., which might have remained in the mixture.

This liquid mixture should be washed over the surface with a rough brush called a "kunchi," and then well rubbed with a rounded stone. Sometimes a thicker liquid lime putty is prepared, and this is spread on the surface with large trowels, and thoroughly rubbed till it becomes smooth and even. It should not be permitted that layers of plaster exceeding ½" be used for the first or second coats as it is nearly impossible to work them up sufficiently. The final coat should always be very thin.

140. White lime plaster is made of varying proportions. A good plaster for outdoor work is made with one part white lime and one part soorkhi. The soorkhi should be made from bricks which are neither underburnt nor overburnt.

Horse, buffalo or goat hair, or finely chopped "sun" should be mixed in the proportion of 1 chitak to 4 cubic feet of the lime and soorkhi mixture before water is added. The water should then be added and the mixture stirred, as described above for kankar lime plaster.

For inside walls of buildings a good plaster is made in the proportion of 1 part white lime to 1 part of coarse sand. A larger proportion of sand is frequently added, but when this is done, the plaster is not strong and is liable to suck up the white-wash or colour-wash too quickly.

similar, and assuming that good materials are used, the excellence of the work depends mainly on :—

(a) The proper raking out, cleaning and damping of the joints and the surfaces to be plastered ;

(b) The fineness to which the lime used for the plaster has been ground ;

(c) The care and time taken in patting the mortar laid in the different coats of the plaster, and in keeping up this patting till the mortar has dried ;

(d) The care and time taken in keeping the work damp.

Good plastering cannot be done hurriedly and it should never be done during the hot weather, as then it dries too quickly and due to the heat it is impossible to work up the plaster properly.

138. For ceilings and partition walls thin coatings of plaster are laid on thin strips of wood called *laths* or on wire netting. Wooden *laths* are about an inch wide and $\frac{1}{4}''$ thick, and are nailed to the rafters of the ceiling or to the wooden framing of the partition walls. A space of about $\frac{3}{8}$ inch is left between the *laths* ; the plaster is pressed through this space, a protuberance at the back is formed, which, when it hardens, makes a key and holds the plaster in position. This first coating is called the "rough" or "scratch" coating ; it is about $\frac{3}{8}$ inch thick and is laid roughly. When it is nearly dry diagonal lines are scratched across it with a pointed stick to give a good hold for the next coating. The second coating is thinner than the first, but is of much the same consistency ; the third coating is only about $\frac{1}{8}$ inch thick and is made of pure white sand with a larger proportion of white lime than in the first two coatings. Horse, bullock or goat hair or chopped "sun" or wood fibre are mixed with the first two coatings to make the mortar more cohesive and less liable to crack. For fine polished work the final coating may have an admixture of plaster of Paris, or the plaster may be made as described in paragraph 142. Plaster on masonry walls generally consists of two coatings—the rough and the final.

139. Kankar lime plaster is used for work in water, or where the work may be exposed to the action of water. The best proportions for the mortar which is to be used varies with the chemical constituents of the kankar. In some places, such as in the north of the United Provinces, sand is seldom used, whereas in the south, where the kankar more resembles white lime, it is necessary to add sand in order that the plaster

may be preserved from cracking. For plaster work on the Solani aqueduct, near Roorkee, the following proportions were used :—

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Water is added very gradually, and the mixture is then carefully stirred and worked up till a smooth appearance is produced.

If the walls to be covered are uneven, their irregularities should first be carefully filled in with concrete made of fine shingle or small pieces of hard bricks mixed up with the mortar mentioned above. When this has nearly set, a coating of plaster from ⅜" to ½" thick should be laid on and brought to a smooth and even surface with a long straight edge. It should be then well beaten with small pieces of wood or strips of bamboos. This patting should be continued day after day till the plaster coat hardens. If this is not done, the plaster will crack badly; but if the patting be continued after the plaster has hardened, it will cause injury to the work. The final coating consists of a mixture similar to the lower coating, but much more water should be added to it, and the ingredients should be strained through a coarse cloth to remove any coarse pieces of burnt kankar, etc., which might have remained in the mixture.

This liquid mixture should be washed over the surface with a rough brush called a "kunchi," and then well rubbed with a rounded stone. Sometimes a thicker liquid lime putty is prepared, and this is spread on the surface with large trowels, and thoroughly rubbed till it becomes smooth and even. It should not be permitted that layers of plaster exceeding ½" be used for the first or second coats as it is nearly impossible to work them up sufficiently. The final coat should always be very thin.

140. White lime plaster is made of varying proportions. A good plaster for outdoor work is made with one part white lime and one part soorkhi. The soorkhi should be made from bricks which are neither underburnt nor overburnt.

Horse, buffalo or goat hair, or finely chopped "sun" should be mixed in the proportion of 1 chitak to 4 cubic feet of the lime and soorkhi mixture before water is added. The water should then be added and the mixture stirred, as described above for kankar lime plaster.

For inside walls of buildings a good plaster is made in the proportion of 1 part white lime to 1 part of coarse sand. A larger proportion of sand is frequently added, but when this is done, the plaster is not strong and is liable to suck up the white-wash or colour-wash too quickly.

It is a good thing to sprinkle the plaster during the process of beating with a mixture of $3\frac{1}{2}$ seers of "gur" (coarse sugar) dissolved in half a barrel of water to which 2 seers of bael fruit is added. This mixture quickens the setting of the mortar, and improves the quality of the plaster. Gur is, however, seldom entered in the specification as it is very hard to keep the workmen from eating it.

141. Kacha or mud plaster is composed of stiff powdered clay and chopped straw, mixed dry, and in equal proportions. In the hills pine needles are often used in place of the chopped straw. Water is then added, and the mixture allowed to soak for a few days. It is then worked up with *phaorahs* and the feet, and more water added, as may be required, till the whole mass assumes the consistency of stiff mortar. The mixture is then spread over the surface to be covered with the hand or with a trowel, and worked into an even surface with a wooden straight edge. The plaster is then allowed to dry, and any cracks which form are filled with liquid cow-dung. The whole surface is then washed over with a liquid mixture of cow-dung and clay by hand or by a trowel and straight edge. This process is known as "leeping." The cow-dung and clay mixture mentioned above is prepared by first steeping the cow-dung in water and removing the grass straw or other impurities. Equal quantities of cow-dung and powdered clay are then mixed with water and thoroughly worked up.

142. Polished plaster* is made in four stages; first the rough coat, secondly the "kara" coat, then the polishing, and finally the fixing. The rough coat is made in the ordinary way, as has been described in previous paragraphs, and when this has been thoroughly beaten with wooden beaters and has nearly dried, the second coat is added. Before this coat is added, the surface of the rough coat should be washed and all greasiness removed by rubbing it with a piece of stone. The second coat is made of two parts freshly slaked white lime and one part of pure white stone, ground into a paste by the addition of a sufficient quantity of water. This mixture is applied with a trowel and "floated" with a straight edge, and beaten with wooden beaters.

The third stage consists in the application of a specially prepared polishing paste. For this the second coat is washed, and the paste is applied with a brush. Three very thin coats of the paste are given, and the surface each time is rubbed with a piece of white marble. Then two

* The details of this process were given me by a mistri who was renowned for the excellence of his work.

more coats of white lime paste are added with a brush, and the surface is then rubbed with pieces of wood. When just dry, the surface is given a wash of white lime and rubbed with a polishing stone.

The surface is then washed with cocoa-nut water, and finally rubbed with a cloth pad, till it becomes glossy and translucent.

The polishing paste consists of four parts white lime paste with 1½ to 2 parts of "jhiki" or pure white stone powder. These are mixed with a trowel and made into a thin paste.

The white lime paste is made as follows :—

A solution of slaked lime is passed through muslim, 4 seers of curds are added to each maund of slaked lime and the mixture passed through calico. This should stand for 20 to 25 days, the water being changed every third or fourth day. Only very pure or distilled water must be used.

The "jhiki" or powder is made by powdering marble and sifting it through fine muslin.

To make the polish permanent, the following solution is applied to the surface and rubbed with a cloth pad :—

Cocoa-nut ...	... 4 chitaks	(rubbed in water).
Country soap ...	... 2 „	(dissolved „).
Clarified butter (ghee)	... 2 „	
Slaked white lime	... 4 „	(dissolved in water).

The solution should be heated to the boiling point, and applied while lukewarm.

143. Polished cement floors.—The ground floors of most Indian dwelling houses are made with a thin layer of concrete covered with lime plaster. This surface, however, wears out readily unless it is covered with matting or darries. A much more durable, more sanitary and prettier flooring is made with cement in the following manner.

The lime concrete base is laid one inch below the required floor level ; it is then thoroughly cleaned and the top surface roughened and watered before the cement flooring is laid. A mixture is made consisting of two parts dry cement with three parts of clean sharp sand and spread over the lime concrete. Water is then poured on till the whole surface is semi-liquid ; it is then levelled off true with trowels and wooden straight edges.

If the floor is to be coloured red, a mixture is made of 1 part finely ground red powder, called "Hiranji," with 3½ parts of water, and this is poured over the floor and worked in evenly over the surface with

wooden straight edges. The floor should then be sprinkled over with a *dry mixture of 1 part red powder with 2 parts of cement, and the paste* so formed should be worked in with trowels and straight edges. As soon as the floor begins to dry it can be polished to any degree that may be required. In the same manner any other colour that is desired can be produced by the admixture of other colouring matters.

The whole of a floor must always be finished on the same day that the work has been commenced.

It is almost impossible to prevent large floors from forming temperature cracks; but if they are marked even with very shallow lines into any convenient size of squares, the cracks will form along these lines and will not be noticeable later on.

APPENDIX I.

Notes on Mortars.

144. Full details regarding the qualities, characteristics and manufacture of materials used in masonry work are given in the Building Material Manual. A clear knowledge regarding "Mortar" is, however, so essential to the Engineer that the following brief notes are given, even though they may appear in a more detailed form elsewhere

145. Every kind of mortar consists of a mixture of burnt lime and other ingredients which vary according to the class of work and purpose for which the work is required

Limes may be divided into two classes, *viz*, Fat Limes and Hydraulic Limes

Pure limestone, or Calcium Carbonate ($Ca\ Co_3$), is the base of all limes, and a fat lime is one where there are very few impurities

Pure limestone ($Ca\ Co_3$), when burnt, gives off carbon dioxide ($C\ O_2$), and becomes quicklime ($Ca\ O$), which, when mixed with water, forms [$Ca\ (O\ H_2)$], or slaked lime.

If this slaked lime is mixed with water and allowed free access to the air, it will harden or set by absorbing carbon dioxide from the air, and form once more calcium carbonate

Hydraulic limes are those which are capable of setting under water without the action of air. They are prepared from limestones which contain a fair percentage of clay (Silicate of Alumina), and when burnt, a chemical mixture of aluminate or silicate of lime is formed The subsequent setting action is due to the crystallising of the Aluminate or Silicate

In the case of both fat and hydraulic limes, it is essential to keep the mortar damp while the setting action is in progress because water is necessary to allow the chemical action to take place For this reason the Engineer must insist on all masonry work being kept damp for 15 days after the work has been completed.

146 **Portland cement** —Portland cement is the most perfect hydraulic binding mixture in ordinary use

Roughly the constituents of Portland cement are —

Lime	...	61 per cent.
Silica	...	25 ,,
Alumina	...	8 ,,
Oxide of Iron	...	4 ,,
Magnesia	...	2 ,,

Lime and clay containing these proportions are thoroughly mixed wet, and are then dried in cakes and burnt till vitrification nearly takes place It is then ground into fine powder and stored

Two to four parts of sand are generally mixed with cement before use, and this mixture is sufficiently strong for all ordinary purposes.

147. **Limes** —Limes prepared by burning kankar nodules or limestone are generally used in India

There is little to choose between the two if properly prepared and used, but kankar lime is recommended where it is available, as it is hydraulic and less likely to deteriorate.

148. **Kankar Lime** —Kankar in the raw state usually contains a certain amount of clay (Silicate of Alumina), which, when burnt, renders the lime hydraulic. It sometimes, however, has a tendency to be "fat", when there is not a sufficient quantity of clay in the mixture In such cases a little "**Surkhi**," or burnt clay, should be added, as it has the power of rendering the lime more or less hydraulic.

Sometimes kankar contains impurities which are harmful, if present in excess. For instance, if there is too much magnesium carbonate, the resultant magnesia in the lime will cause it to slake slowly with a very small rise of temperature, and the lime so formed will be poor.

It is very necessary to burn some kankar and have its setting properties tested before using it in any important work.

Kankar lime is usually strongest if used plain; in most works, however, some sand or surkhi may be added without danger and the resultant mortar will be cheapened considerably.

The best results can only be obtained by testing each variety of kankar lime with different mixtures, but kankar lime can seldom stand more than 1 part of sand or surkhi to 1 part of lime without undue loss of strength.

Very common mixtures are 1 part of sand to 1 part of lime, or 1 part sand, ½ part surkhi and 1½ parts of lime

149. **Stone or White Lime** —Stone or white lime is obtained by burning a lime stone, and, as it generally has very few impurities in the form of silica or alumina, it is therefore not naturally hydraulic.

It can, however, be rendered somewhat hydraulic by adding surkhi after burning, and, as in any case white lime will set more quickly when mixed with surkhi than when sand is added, the former is therefore more generally used as a diluting agent.

150. The purest white limes burnt in Northern India come from the country round Sutna and Katni

An analysis of some Sutna lime gave the following results :—

Lime	94 per cent
Silicious matter	3 ,,
Oxide or Iron and Alumina ..	2 ,,
Magnesia	1 ,,

Such limes cannot be used plain, and since they are very rich in lime, it is possible to dilute them with a much larger percentage of sand or surkhi than is the case with kankar lime

One part of white lime to two parts of sand or surkhi is a very usual mixture

Sutna and Katni limes can, however, have even more matter added, and a mortar consisting of one part of lime to 2 parts of sand and 2 parts surkhi was used in building the East Indian Railway Bridge over the Sone River.

151 The makers recommend the following mixtures, which, on account of the admixture of surkhi or ashes are stated to be sufficiently hydraulic for wet foundations.

Sand.	Surkhi.	Ashes.	Slaked Lime (Sutna).	
2	2	..	1	= 4 to 1
2	1	1	1	= 4 to 1
2	..	2	1	= 4 to 1

152. Ashes have begun to be used in place of surkhi to a great extent for railway works, as this material is available in large quantities from the refuse raked out of the locomotive fire boxes Of course only ashes from burnt coal can be so used, wood ashes would be quite unsuitable.

153. One of the great disadvantages of white stone lime is the care which must be taken in using it.

It can usually be bought ready slaked, but once slaked it deteriorates quickly, and therefore unslaked lime should always be purchased as it is impossible to say how old the slaked lime may be

The lime will gradually slake from the moisture in the air, especially during the rains; it cannot, therefore, be stored for years with success as kankar lime can be.

Good white lime will double its volume when slaked Dealers therefore always prefer to sell slaked lime even at lower rates.

The greatest care must be exercised in fully slaking the lime before use in any work. For this reason it is usual to specify that the lime must be slaked for 48 hours before use

The best method is to slake the lime in vats or "pukka" cisterns, adding enough water to make a paste This paste must be mixed with the surkhi and sand and used before it has dried

Only by thus soaking the lime can it be made certain that no lumps of unslaked lime will go into the work *Any slaking that takes place after the lime has been used will damage* the work and make it look very unsightly.

Stone lime is generally cheaper than kankar lime and for many works is just as good, but it always requires more care

154. **Surkhi.**—The surkhi used with lime is almost always obtained by breaking up the broken bricks and refuse over from the brick kiln, though sometimes clay has to be burnt for this purpose.

Engineers differ as to what class of bricks make the best surkhi. Some claim that 1st class bricks are best because the clay is fully burnt, others say that 3rd class are best because they can be powdered fine, which is very difficult with hard well burnt bricks Most Engineers, however, agree that 2nd class bricks make very good surkhi, so these should be used where possible

155. **Sand**—Sand used in mortars should always be as coarse as obtainable, and of sharp grains, free from clay or other impurities.

156 **Grinding and mixing**—Cement is purchased ready ground, and white stone lime powders when slaked, and therefore these need no grinding before mixing with the other ingredients of the mortar Kankar lime, however carefully burnt and picked afterwards, always has some bits which are not fully burnt, and these must be ground up fine before mixing to form the mortar.

For large important works disintegrators are used for this purpose, and a 2½" size disintegrator can grind from 80 to 100 cubic feet of kankar lime per hour with a 10 H. P. portable engine to drive it.

For smaller works the grinding and mixing can be done at the same time in bullock "chakkis" These are generally made to hold about 40 to 80 cubic feet of mortar, and the whole is mixed and ground wet in from 2 to 4 hours, that is, two or three "chakkis" full are turned out daily

One hundred cubic feet of dry mixture will turn out about 70 to 75 cubic feet of wet mortar after mixing.

In large works the kankar lime, after it has been disintegrated, is mixed with the sand or surkhi and ground wet in mortar mills (these are usually run in pairs driven by portable engine) One pair of 7 feet pans will easily turn out 50 cubic feet of wet mortar per hour

Wet grinding should also be done where kankar lime is used.

157. **Mortar required**—The amount of mortar required for the different classes of masonry differs considerably.

For ordinary stone ballast concrete, about 45 cubic feet of mortar will fill the interstices; it is better however to specify that 50 cubic feet shall be used for every 100 cubic feet of concrete. One hundred cubic feet of brickwork, on the other hand, only

takes 30 cubic feet to fill the joints, while rubble stone masonry may take anything from 40 to 60 cubic feet according to how the stones are laid.

158. As already explained, it is very difficult to tell from the look of any lime whether it will make a good mortar or not and whether it will be hydraulic, or what proportion of sand or surkhi should be added to get the best results.

By far the simplest method of testing lime is to actually build several small pillars using different proportions in the separate mortars likely to be employed, leave these to set for a reasonable time and then dismantle and study the results.

This, however, is unsatisfactory unless a very long period, say 6 to 9 months, can be given up to experiments before work is started. Some limes set quickly and are apt to make the Engineer think they are better than they really are, while others are often rejected because they take a long time to set.

The best recognized method is to test the tensile strength of the various mortars by means of a standard testing machine (described in all treatises on materials).

Briquettes are made in moulds so that they have at the narrowest portion a section of one square inch exactly. Some of these are broken in the machine after 7, 15, 30, 45, 60, 90 and 120 days, and the results tabulated.

The briquettes are kept under water for a varying period after being made so that the hydraulic properties may be fully tested.

Even this method is apt to lead the Engineer astray, for many limes which give the poorest result in the laboratory are found to do quite well in actual work.

Experience and common sense backed by a few simple experiments are therefore often the best guides.

Engineers differ greatly as to the tensile strength a mortar should give if it is to be suitable for use in masonry works. Some even go so far that any mortar will be used which will ultimately give a tensile strength of only 40 pounds per square inch.

A usual mixture should, however, give a strength of over 100 lbs. per square inch if the lime is at all good, and some very good kankar limes will give 300 lbs per square inch eventually.

A few average tests are given as a guide as to what may be expected after various periods of time :—

Material.	*Proportions.*		*Tensile strength per square inch after days.*					
	Lime or cement.	Sand.	15	30	45	60	90	120
Cement ..	1	..	400	500	500	500	500	300
	1	1	250	300	300	300	300	300
	1	3	180	200	200	200	200	200
Kankar ..	1	..	50	80	120	160	180	200
Lime ..	1	1	35	70	100	120	140	160

Different cements and limes, however, differ so much that these are only given as a rough guide, and even results as shown are never obtained in practice.

A slightly different method of mixing the mortar or preparing the briquettes will alter the subsequent tests so much that, as stated before, the Engineer must often rely on his common sense and experience, if he is to obtain the best results on the works themselves.

159 Finally, the following points must always be most carefully attended to, if the resultant masonry is to be satisfactory

1. The lime must be fully burnt.
2. Fat lime should be brought to the work unslaked, but should be slaked at least 48 hours before use
3. In the case of kankar lime, all under or overburnt nodules should be picked out before grinding
4. *Lime must be finely ground and mixed carefully, if there are any admixtures,* before use.

   Kankar lime mortar should always be ground in a wet state before use on works
5. Mortar should be tested in some manner and not used unless these tests show that it is satisfactory.
6. Masonry should be kept damp for 15 days after being laid, to give the necessary dampness to enable the mortar to set

APPENDIX II.

Specification for Brickwork.

160. **Description of brickwork**—First class brickwork will consist of stock-made bricks of uniform colour and shape, thoroughly well burned, and of a deep red or copper colour. Each brick must be square and well shaped, must ring clearly when struck and must be perfectly sound in all respects

Second class brickwork will consist of bricks which are thoroughly burned, sound well, but are not so perfectly shaped as first class bricks. They will be much the same as first class bricks, with the exception that the colour and shape need not be of quite so high, or uniform a quality. The inner bricks may be of a lighter colour, but for all face work bricks should be selected for uniformity of colour

There will be no difference whatever between first and second class brickwork, either in the mortar used, in the method of laying, or in the bond

161. First class bricks are to be made of good brick earth, well kneaded and free from *kankar* or vegetable matter; they are to be sand moulded, well shaped and square, with sharp regular arrises, free from cracks or shakes ringing clearly when struck, burnt to an uniform deep red or copper colour, not vitrified, but hard enough to stand exposure to the action of water

Second class bricks are similar to first class, except that the colour need not be so deep or uniform. They must, however, be well burnt, fit for backing and dry walls, but need not be hard enough to resist the action of water.

162. **No brick shall exceed the following dimensions**:—Length 10 inches, breadth $4\frac{3}{4}$ inches, thickness $2\frac{3}{4}$ inches, or shall be less than $9\frac{3}{4}$ inches in length, $4\frac{5}{8}$ inches in breadth, and $2\frac{5}{8}$ inches in thickness.

163. All bricks are to be soaked in the tanks for at least 12 hours before being put into the work.

164. The bond to be used in all brickwork will be "English" bond, see plate 2, and no half-bricks or brick-bats will be allowed to be used except where necessary to complete the bond.

No stretcher is to be less than three-quarters of a brick

The use of half or three-quarter bricks is to be strictly limited to the requirements of the preservation of the bond.

165. The use of bats is as a rule prohibited, but in special cases, such as the filling of arch haunches and massive abutments, the use of a percentage of bats may be permitted

In such special cases the percentage of bats to be used should be specified, and with a *proviso* that every fourth course shall be free from bats except where required for the bond.

166. Mortar is to be used as stiff as is consistent with the proper filling of the joints, no one of which is to exceed a quarter of an inch in thickness

Mortar is to be delivered on the work from the mills, of the proper consistency, and the use on the work of water pots for thinning the mortar is strictly prohibited.

167. Every brick is to be drawn up in the mortar and firmly bedded with a wooden mallet.

To ensure that the frog of the brick is filled with mortar, bricks are to be laid in the work with the frog upwards.

168 The top of all brickwork is to be kept covered with water when brick laying is not actually in progress, and also for 2 weeks after completion of the work.

For this purpose it should be provided with a mortar *dowah* all round the edge, and be divided into *kyaries* or compartments.

169. The face of each unbattered wall is to be perfectly vertical, and the bed of each course is to be level across and perfectly horizontal unless otherwise ordered

170. Battered or curved walls and ornamental work are to be built in strict accordance with templates made up from the working drawings In battered walls where the course beds are ordered to be horizontal in place of square to the face, the face bricks are not to be cut, but are to be stepped back to give the required batter, or special moulded bricks may be used

171. Where possible, the work will be carried up regularly throughout and, except where required by the design, no part is to be more than 3 feet higher than the rest.

Returns, counterforts, buttresses, etc, are to be built course by course with, and bonded into, the main work.

172 When the entire work cannot be carried up in even courses the break is to be left in regular steps, each of a length at least 1½ times its height

173 The surface of each course is to be thoroughly cleaned from all dirt before another course is laid on the top of it.

Should the mortar in any course have begun to set, the joints must be raked out to a depth of one inch before another course is laid, and the whole surface well levelled with water for 2 days before the new work is commenced. But when the top course has been exposed to the weather for any length of time it should be removed, and the surface of the second course thoroughly cleaned and wetted before any more courses are added.

174 The joints of all work which is to be pointed or plastered are to be raked out to a depth of ½ inch before the mortar has begun to set.

In cases where the mortar has unavoidably been allowed to set the joints are to be raked out with a tool made for the purpose, and are on no account to be cut out with any sharp instrument And in all cases the surfaces must be thoroughly soaked before the new mortar is applied

175. In brick-on-edge flooring the course below the brick-on-edge should be laid frog downwards, care being taken that the frog is filled with mortar before the brick is laid.

176 Brick on edge is to consist of picked first class bricks laid in mortar. So long as the bricks are perfectly shaped they may be slightly overburnt.

The mortar joints should be as fine as possible and the bricks are to be laid with a break of joint equal to half the length of the brick

177. **Brickwork in clay.**—Walls will be built of bricks laid in clay when ordered or specified. This work will be as specified for brickwork in mortar with the following exceptions:—

(*a*) The cementing material will be well kneaded clay instead of mortar.

(*b*) The top courses of unfinished work need not be kept covered with water.

178. The mud mortar is to be made of stiff white or red clay according to locality, which is to be broken up into a fine powder freed from stones, grass, or other impurities. It is first mixed with water on a brick or wooden platform and well worked up with the feet to the consistency of clay for brick making It is then to be gradually thinned with water until it assumes the consistency of stiff mortar when it will be ready for use.

179. **Sun-dried bricks in clay mortar**—Walls will be built of sun-dried bricks in clay mortar when ordered or specified. They will usually consist of unburnt stock bricks laid as specified for burnt brickwork in clay.

APPENDIX III.

Specification for Stone Masonry

180 The masonry to be used will be ashlar work, coursed or uncoursed rubble or other variety, as may be directed by the Divisional Officer, or as indicated on the working drawings, laid in mortar.

181. The mortar to be used will be as specified for brickwork.

182. The specifications as to watering the work and carrying it up evenly, as laid down for brickwork, are to be adhered to for stone masonry.

183 **Ashlar work.**—Generally speaking, for all ashlar work, the contractor will be supplied with the exact dimensions of each stone or with a plan of each course of masonry showing the necessary dimensions

184 Ashlar work will have its beds and joints finely dressed, free from any winding, and true and square in every respect

185 All joints and beds will be perfectly vertical and horizontal respectively; they will never exceed ¼ inch in width or depth, and each stone will be well set and flushed up in mortar

186. All joints and beds of ashlar work will be constructed as laid down in paragraph 185, but the outer face or faces may be *rock-faced, finely chisel dressed rock-faced with chisel margin etc.*, or as may be described, either in the specification, or on the ground

187 Ashlar work shall never be laid in courses of less than 10 inches in height: no *stone should be of less volume than 1½ cubic feet, 1/5th of the face should be headers,* and no stone should have a less width of bed than 1½ times its height.

188. When ashlar quoins or ring stones are provided, the arrises must be dressed clean, sharp, true and free from all winding, in the former quite plumb and vertical, and in the latter lying exactly in the line of the perimeter of the circle indicated or directed.

189. **Coursed rubble**—Coursed rubble will be laid in courses varying in height as may be most convenient and economical, according to the nature of the stone procured from the quarry, as regards either the depth of the natural beds of the stone or the manner in which it will cleave, but no course should be less than 6" in thickness.

190. Coursed rubble may have its courses either of equal or of unequal height but in the latter instance, the deeper courses must be laid towards the bottom of the structure, and may gradually get shallower within the limit given above as the wall progresses in height.

191. All buildings constructed with coursed rubble masonry should be supplied with ashlar quoins of the height of one or two courses, and care should be taken, when equal courses are specified, that the height of the wall is divided into an exact number of courses, and an exact number of quoins.

192. All beds and joints must be perfectly true, both horizontally and vertically throughout They must never be more than half an inch in width or depth respectively, the line of each course must be perfectly level and free from winding, and no joint must overlie another less than 4½ inches, measured on the face of the wall.

193 No stone should be used which is less than a cubic foot in size, its bed must never be less than 1½ times its height.

194 One-fifth of the face of the wall should be headers, and in walls up to 3 feet thick, all headers should be through-stones. All other stones shall be in half bond, or should overlap each other never less than 1/3rd of the width of the wall.

195. Every stone must be carefully and truly laid, and will be flushed up in mortar as laid down under brickwork.

196. **Rubble or random uncoursed rubble**—The stones will be laid at random without being brought up to any level courses, each stone will be laid on its quarry bed, will be bedded in an ample supply of mortar, and will be wedged or pinned strongly into its position in the wall by spalls or chippings, which may show on the face.

197. No fixed rule can be laid down for sizes of joints, but they must be kept as small as possible. This work is subject to the same rules for through or bond stones as specified above for other classes of rubble masonry

198. **Masonry in clay.**—When any of the above kinds of stone masonry is specified to be laid in clay, it will be carried out as specified for mortar except that—

(a) the cementing material will be well kneaded clay instead of mortar,

(b) the stone used need not be soaked previous to use,

(c) the top course of unfinished work need not be covered with mortar.

199. The clay will be prepared as specified under Brickwork, paragraph 178

200. **Dry rubble**—All the above kinds of masonry can be carried out dry, that is without the use of mortar This sort of work is in very general use for breast and retaining walls in hill roads,

201 In these cases the front batter should never be less than ¼, but where base room can be obtained, it may advantageously be made ⅓ The back slope should be about ¼ The coursing will always be normal to the face of the wall, and there will always be a projection or broad footing at the base The top of the wall should not be less than 2 feet thick In surcharged walls this thickness must be increased to 3 feet

202. Through bond, from front to back consisting of a single stone or of several stones, put together, must be given in every course at every 5 feet along the face of the wall. Where bond stones of length equal to the thickness of the wall are procurable, they are always to be used.

APPENDIX No IV.

Specification for Boulder Masonry.

203. Boulder masonry will consist of three classes as follows :—

1st class —In this class only the best and largest boulders will be selected. They will be neatly squared on all six sides, and the blocks will be laid in the same way as specified for coursed rubble masonry. The mortar joints must not exceed one inch, but the mortar need not be ground Owing to the extreme toughness and want of lamination in boulders, it is very difficult and costly to square them to proper shape; but at the same time if they are squared on all six sides and the courses properly built up, the walling can be made of smaller section than in the second and third classes, so that the ultimate cost is not much more.

In works which have to withstand the action of water it is advisable to point the joints with Portland cement.

2nd class —In this class the boulders will be split and roughly dressed, and the blocks built up in the same manner as for random uncoursed rubble The undressed surfaces of the stone should be on the outside.

3rd class —In this class the boulders will not be split. The interstices between the larger boulders should be filled up with smaller stones and mortar freely used. Such masonry is only suited for dry walling which is not submitted to any great pressure.

204. In important works it is advisable to introduce several courses of brick bond, at regular intervals apart, in order to distribute the pressure more evenly The appearance of a building will also be improved if the corners and arches and jambs of doors are faced with brick.

APPENDIX, No V

Specification for Archwork

205 Archwork to be of picked first class bricks laid in mortar

206. In bridges with elliptical or with 5-centered arches, the portion of the arch near the haunches will be built in concentric rings bonded by headers at every natural coincidence of joint; where the natural coincidence of joint does not occur in less than eleven bricks, a forced coincidence must be made at every tenth brick by closing with a chipped or dressed brick.

207. For the remainder of the arch English Bond is to be used The stretchers must be laid without chipping, the summer to be preserved by dressing the headers only.

208. In elliptical arches the backing at the haunches is to be built simultaneously with turning the arches The backing to be built to a height of 7/10ths of the rise before the centering is struck.

209. In segmental arches English Bond is to be used Arches of small spans are to be built in concentric rings bonded at every tenth brick at least

210. Archwork is to be built up equally from both haunches, and the work to be carried on without intermission The joints are to be kept as fine as possible and of equal thickness, and each brick is to be completely embedded in mortar.

211. When the work is built in concentric rings, no bricks are to be chipped or dressed, except those required to secure a forced coincidence of joint

212 Centerings of either earth or timber may be used. Wooden centerings should be used in a series of bridges of the same span, in elliptical arches and in arches of very large span.

213. In skew arches the spiral courses are to be calculated and traced on the centering before the skew backs are commenced When the angle of skew is not less than 80°, direction of the courses may be everywhere taken perpendicular to the face of the bridge.

214. Centerings should be slacked a little as soon as the arch is keyed, and should be gradually slacked as the arch settles down This gradual slacking should be arranged so that the centering is completely struck at the time the mortar begins to set.

215. This gradual striking cannot be carried out with earthen centerings, and where these are employed the centering should be struck as soon as the arch is keyed.

APPENDIX No. IV.

Specification for Boulder Masonry.

203. Boulder masonry will consist of three classes as follows :—

1st class.—In this class only the best and largest boulders will be selected. They will be neatly squared on all six sides, and the blocks will be laid in the same way as specified for coursed rubble masonry. The mortar joints must not exceed one inch, but the mortar need not be ground. Owing to the extreme toughness and want of lamination in boulders, it is very difficult and costly to square them to proper shape; but at the same time if they are squared on all six sides and the courses properly built up, the walling can be made of smaller section than in the second and third classes, so that the ultimate cost is not much more.

In works which have to withstand the action of water it is advisable to point the joints with Portland cement.

2nd class.—In this class the boulders will be split and roughly dressed, and the blocks built up in the same manner as for random uncoursed rubble. The undressed surfaces of the stone should be on the outside.

3rd class.—In this class the boulders will not be split. The interstices between the larger boulders should be filled up with smaller stones and mortar freely used. Such masonry is only suited for dry walling which is not submitted to any great pressure.

204. In important works it is advisable to introduce several courses of brick bond, at regular intervals apart, in order to distribute the pressure more evenly. The appearance of a building will also be improved if the corners and arches and jambs of doors are faced with brick.

APPENDIX. No. V.

Specification for Archwork

205 Archwork to be of picked first class bricks laid in mortar

206 In bridges with elliptical or with 5-centered arches, the portion of the arch near the haunches will be built in concentric rings bonded by headers at every natural coincidence of joint, where the natural coincidence of joint does not occur in less than eleven bricks, a forced coincidence must be made at every tenth brick by closing with a chipped or dressed brick.

207. For the remainder of the arch English Bond is to be used. The stretchers must be laid without chipping, the summer to be preserved by dressing the headers only

208. In elliptical arches the backing at the haunches is to be built simultaneously with turning the arches The backing to be built to a height of 7/10ths. of the rise before the centering is struck.

209. In segmental arches English Bond is to be used. Arches of small spans are to be built in concentric rings bonded at every tenth brick at least.

210. Archwork is to be built up equally from both haunches, and the work to be carried on without intermission The joints are to be kept as fine as possible and of equal thickness, and each brick is to be completely embedded in mortar.

211. When the work is built in concentric rings, no bricks are to be chipped or dressed, except those required to secure a forced coincidence of joint

212 Centerings of either earth or timber may be used. Wooden centerings should be used in a series of bridges of the same span, in elliptical arches and in arches of very large span.

213. In skew arches the spiral courses are to be calculated and traced on the centering before the skew backs are commenced. When the angle of skew is not less than 80°, direction of the courses may be everywhere taken perpendicular to the face of the bridge.

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215. This gradual striking cannot be carried out with earthen centerings, and where these are employed the centering should be struck as soon as the arch is keyed.

APPENDIX No VI.

Specification for Concrete.

216. Concrete for ordinary foundations is to consist of 3 parts 1½" gauge brick ballast to 1 part kankar mortar; when stone ballast is used 2 parts ballast to 1 of mortar are generally used.

The brick ballast is to be cleaned and soaked in water tanks prior to mixing, for not less than three hours.

217. The mixing is to be done on a floor of bricks laid flat, frog downwards, or on a portion of the completed work by laying out the ballast evenly and spreading the proper proportion of dry lime or wet ground mortar over it.

The materials in the stacks should then be turned over with shovels or phaorahs and thoroughly mixed at least twice from end to end, sufficient water being added to turn the lime into a thick paste

218. After mixing, the concrete is to be laid in layers not exceeding 8 inches in thickness and rammed with iron rammers, until the lime flushes up to the surface, when the ramming must at once be stopped, as further ramming is injurious. The layer will then have consolidated to about 6 inches in thickness.

219. Springs in open foundations may often be staunched by laying over them a layer of concrete thicker than above specified, and ramming it lightly. In this case the proportion of mortar should be increased. The thickness of the layer of concrete and the amount of consolidation must be determined by the condition of the soil in the foundations and the force of the springs

220. Should a spring be too strong to be staunched by this means it should be left open and allowed to run freely through an iron pipe, which can be plugged later on with Portland cement, either pure or mixed with sand, or a small water-tight wall may be built round it allowing some space, and after the water has risen to its maximum level, it can be staunched with cement concrete laid quickly in the still water, and above its level and weighted with bricks.

221. In very slushy foundations a three-inch layer of third class brickbats should, if available, be rammed below the first layer of concrete; or rough grass matting may be laid down. These prevent the slush being forced up into the concrete when being rammed. If the slush rushes in too freely from the sides of the excavation, sheet piling should be used to form a cofferdam, *but this is best overcome by the provision of drains round the* work.

222. Concrete is not to be thrown from a height but must be deposited gently in position.

223. The surface of concrete in process of consolidation is to be kept sprinkled with water, to compensate for loss by evaporation, but great care should be taken that excess of water is not used.

The surface of concrete laid above spring level is to be kept wet, when work is not in progress, for at least 10 days after completion.

224. Pumping or baling should not be allowed from open foundations, which have become filled with water after the concrete is laid, until it has set, or the lime will be washed out.

225 The surface of each layer should be thoroughly cleaned from dirt and roughened with picks, before another layer is laid above it Before the new layer is laid a coat of plaster should be roughly laid.

226. Concrete in hearting deep wells.—Foundation wells may be hearted either by plugging the bottom, unwatering, and ramming in ballast concrete, or by laying concrete by means of skips without unwatering.

227. Shallow wells may be plugged with equal parts of kankar lime and sand ground into mortar and deposited in skips. The well is then unwatered, and the remainder of the hearting consists of 125 parts kankar or brick ballast broken to 1½" gauge, 30 parts kankar lime and 15 parts sand, rammed in 8" layers

228. Concrete containing certain proportions of Portland cement should be used where quick setting, extra strength, or resistance to the action of water are required

Such cases often occur in carrying out repairs to masonry which will be exposed to the action of water immediately after the masonry is built

229. Various proportions of the different materials are used in this class of concrete, and the following are laid down as a genera guide —

Ballast ¾" gauge 6 parts		Ballast ¾" gauge 6 parts
Portland cement 2 „		Portland cement 1 part.
Kankar lime 1 part	or	
Sand 1 part		Kankar lime 2 parts.

The former is the quicker setting of the two When springs have to be dealt with the proportion of kankar lime should be diminished, and that of Portland cement increased.

230. When Portland cement and kankar lime are used together, the lime should, as far as possible, be of the same fineness as the cement

The cement and lime should be very thoroughly mixed in a dry state before being mixed with the other materials, for on this intimate mixture depends to a large extent the good quality of the concrete.

APPENDIX No. VII.

Specification for Portland Cement Concrete.

231. The proportion of materials in Portland cement concrete varies with the nature of the ballast and the nature of the situation of the concrete. Sufficient mortar should be used to entirely fill the voids in the ballast. The proportion of materials generally varies between one part of Portland cement, two parts of sand and three parts of ballast, and one part Portland cement, three parts sand and six parts ballast. The sand should be perfectly clean coarse sharp sand.

232. The cement used must be of a well known brand. Care must be taken that the cement be not too fresh, in this case it should be laid out on a floor for a few days under cover, in order to get rid of any heat, which would cause it to blow or swell in setting. If exposed thus in dry weather for some time, up to three weeks, it increases in both strength and bulk.

233. Cement concrete will be mixed and laid as specified under concrete, but the following additional precautions must be taken —

The ballast after having been well soaked should be allowed to dry externally and be mixed first with dry sand and cement. Water should not be added until just before it is intended to lay the concrete, it should be poured on gently through the rose of a watering pot, care being taken that the mass is not allowed to become too fluid in consistency. It should be laid as soon as mixed and all ramming necessary must be done within two hours from the time the materials are first wetted. On the following day it should be covered with water and kept so for 15 days. In places where this cannot be done wet sand is to be used instead of water.

APPENDIX No. VIII.

Specification for Plum Concrete.

224 Plum concrete consists of large stones called "Plums" embedded in concrete. The specification is similar to that given for concrete (Appendix No V) The proportion of plums should not be more than 25 per cent, and the plums should not be less in size than 5 cubic feet. Plums should be placed sufficiently far apart to allow of the concrete being fully rammed between them, and should be placed as unevenly as possible, so as to break joint in all directions. Stones must also be placed so that the greatest width is at the bottom, and the least at the top. Rough stones must not be allowed as the concrete cannot be properly filled round the stone.

APPENDIX No. IX.

Specification for Pitching.

235. Pitching is to be of block kankar, stone or brick, as may be specified. Where there is heavy scouring action a special form of pitching, composed of blocks of brickwork, or rubble in lime or of concrete may be employed Pitching may either be grouted or packed

236 Block kankar or stone pitching should be of the largest blocks procurable, limited by facility of handling with the appliances provided. No block should be less than one cubic foot when rough dressed

237. In pitching slopes, care should be taken to give a good toe, and not to attempt a steeper angle than 1 to 1 An easier slope must be given if the height exceeds 10′.

238 Every effort should be made to give a rough surface on slope pitching, so as to break the velocity by inducing friction In case of bricks, this is easily done, by laying the bricks in herring-bone fashion

239 Where no heavy material exists, it is better to protect the earthwork by continuous walls of masonry than by means of cubes of brickwork or concrete The latter become detached and often roll away, or crumble to pieces

240. **Crates** —Where there is heavy scour in a channel in the neighbourhood of masonry works, and the action of the water is so great that ordinary pitching will not stand, the material may be confined in wooden crates of suitable size, dependent upon the circumstances of the case, care being taken that the bars of the crates are sufficiently close together to prevent material being scoured out The crates should be well made and be constructed of some hard wood which is not perishable under water, and the bars should be securely nailed together with stout nails and, if necessary, bound with wire of about 8 B W G.

241. The crates should, as far as possible, be all of the same size and laid with their upper surfaces on the same level, so that no obstruction may be offered to the flow of water, and where more than one line of crates is required, they should be laid so as to break joint with each other.

242. Care should be taken to see that the top cross bars of the crates are securely fixed, after the latter have been filled with the material.

APPENDIX No. X

Specification for Plaster.

243. **Rough casting**.—Plaster will be composed of Portland cement, kankar lime or white lime mortars. For white lime plaster as fat a lime as possible will be used, on account of the readiness with which it slakes into a fine powder.

244. Plaster will be laid in one two, or three coats, as may be found necessary.

245. Brickwork will never have more than two coats of plaster but masonry may have three, and no single coat shall ever exceed ½ inch in thickness.

246 Previous to the application of the plaster, the joints of the brickwork or masonry must have been raked out to a depth of at least half an inch, and this is best done as the work progresses in construction, and while the mortar is still green.

247. After the joints shall have been raked out, the wall must be cleaned down and kept thoroughly damp for two days before the plastering is commenced.

248. The plaster may then be applied, and, before each coat sets, it must be well beaten with long thin lathes (to consolidate and compress the mortar), until such beating makes no impression on the surface

249. When two or three coats are ordered, the first must be allowed to completely set before the second is laid, and the surface should be left rough, and freely scored all over with the edge of a trowel, to prepare it for the next coat

250. If it be thought desirable, the plaster may, during the process of beating, be well sprinkled with a mixture of 3½ seers of gur (coarse sugar) dissolved in half a cask of water, to which may be added 2 seers of bael fruit this will quicken the setting of the mortar and improve the quality of the plaster.

251 **Floating**.—After the "rough cast" has been applied as above in the number of coats directed or specified, and has become quite firm, the next operation will be "floating," which will be done with a long straight edge called a float.

252. A sufficient quantity of fine plaster should be thrown on the wall so as to allow of its being brought to a completely smooth surface, by drawing over it the plasterer's float backwards and forwards

253. **Rendering or setting coat**.—As soon as the surface is perfectly true and level and quite dry and set, it will be "rendered" quite smooth by having lime putty spread over it with the face of a large trowel, with which it must be rubbed in until it becomes perfectly smooth and even.

254. In order to guard against the setting coat showing numberless fine cracks all over its surface, as frequently happens from the unequal shrinking of the different coats it should not be applied till the previous coat is quite dry, otherwise, being very thin, it will harden from exposure to the air before that previously laid has done shrinking, the result being that, if there is a proper adherence between the two coats, the setting coat will be disfigured by numberless fine cracks; whilst where the coats have not adhered well together, hollows will be found, and the setting coat will be liable to come off at those spots.

255 **Mud Plaster**.—Mud Plaster will be composed of stiff clay and chopped straw in the plains, and of stiff clay and pine spines in the hills in equal proportions in bulk. The clay, after being excavated, is to be spread out to be scorched by the sun. It is then to be reduced to powder and stacked in heaps as required.

256. The straw will then be thrown over the clay and mixed with phaorahs in a dry state till thoroughly incorporated. Water is then to be added, and the whole left for two days to soak. It will then be mixed with the feet and phaorahs, water being added as required till it assumes the consistency of stiff mortar.

257. It will then be spread evenly over walls of roof with the hand or trowel to the thickness of 1 inch on roofs, and $\frac{1}{2}$ to $\frac{3}{4}$ inch on walls, and be floated to an even surface with a straight edge about 3 feet long. The plaster will then be allowed to dry, and the cracks that open out during the process of drying will be filled in with liquid cow-dung

258. **Leeping.**—The surface will then be leeped over with a mixture of cow-dung and clay. This will be done by hand on roofs, and by trowel and float on walls. Care will be taken to preserve all lines, mouldings, etc., that existed previously.

259. The cow-dung is prepared by first steeping it in water to free it from grass, straw and other impurities, then one cubic foot of finely powdered clay is added to one cubic foot of cow-dung, and both ingredients are mixed in a tub and thoroughly worked up together.

APPENDIX No XI.

Specification for Pointing.

260. The joints should be raked out to a depth of at least ½ inch and the face of the masonry should be thoroughly cleansed and watered.

The joints should be raked out with a hooked tool made for the purpose. The joints should never be hacked out with a basuli or similar tool as the edges of the bricks are chipped by doing so.

261. The joints are to be filled flush with kankar lime or cement mortar, as may be specified.

The ingredients are to be ground as fine as possible and should be impalpable powder, not granulated.

262. After flushing the joints, the horizontal lines are marked by stretching a string which is beaten into the mortar with a trowel, and the line so obtained is deepened by running a tool called a jointer (similar to a bent nail) guided by a straight edge along the line, or finishing by other methods as described in Chapter IX, as may be directed by the Engineer in charge.

The vertical lines are then struck with the "jointer" and straight edge.

263 All lines are to be perfectly straight, truly horizontal, or vertical, and the mortar should be so stiff that the pointing tool leaves a clean cut line, with no appearance of ragged edges.

264 Pointing should be done from the top of the work downward, and after completion should be kept well watered for at least seven days

265. Pointing must follow the actual joints and is not to represent false joints.

266 Pointing must be carried out as quickly as possible after completion of the portion of the wall and before the mortar used in the wall has set.

256. The straw will then be thrown over the clay and mixed with phaorahs in a dry state till thoroughly incorporated. Water is then to be added, and the whole left for two days to soak. It will then be mixed with the feet and phaorahs, water being added as required till it assumes the consistency of stiff mortar.

257. It will then be spread evenly over walls of roof with the hand or trowel to the thickness of 1 inch on roofs, and $\frac{1}{2}$ to $\frac{3}{4}$ inch on walls, and be floated to an even surface with a straight edge about 3 feet long. The plaster will then be allowed to dry, and the cracks that open out during the process of drying will be filled in with liquid cow-dung

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APPENDIX No. XII.

Specification observed during the construction of the Lachura Dam, Dhasan Canal

267. **General description**.—The dam is to be constructed of the type section shown in plan No. 1 attached herewith.

Below sub-way level, it will be faced up and downstream with rubble masonry and it will be hearted with concrete.

Above sub-way level it will be of rubble masonry, finished off with ashlar copings and with selected rubble block paving.

268. **Masonry**.—On the upstream face, the face stones must not be less than 2 cubic feet, and on the downstream face they must not be less than *6 cubic feet and, excepting spawls, no stone is to be used in any part of the work of less than ½ cubic feet dimension. A good band must be maintained in the face wall masonry of the facing stones both up and downstream, 1/3 must be laid as headers. The stone must be of sound quality and no stone showing signs of weathering, decomposition or cracks shall be put in the work. All the stones are to be placed on their natural bed. The special face blocks must be bedded in mortar, special care being taken to see that the joint is completely filled and the stones well bedded. With this exception of bedding joints, all the rubble masonry below and up to sub-way level will be set in concrete mortar and no joint is to be of less thickness than 3". The gauge for this concrete mortar is to be not greater than 7/8" ring. The Executive Engineer or his Assistant is to have power to stop quarrying at any place if, in his opinion, the stone is unsuitable, or the quarrying is liable to endanger the stability of the reef on which the dam is to be built. During construction, the work is to be carried up uniformly and a greater difference of level than 3 feet must not occur without the special sanction of the Engineer.

The face joints on both faces of the weir are to be raked out to a depth of 3" for pointing with cement mortar consisting of one part of cement to 3 of fine hard sand by measure, to be slightly stiff, and driven tightly into the joints with wooden implements, and neatly finished off flush.

All the lime used is to be ground by disintegrators and the mortar mixed in a mill. Specification for the mortar is given in the schedule of rates attached. If the quantities actually used in the work are found to differ from those given in the analysis, the rates will be adjusted accordingly.

269. **Concrete**.—The cement concrete used for filling in the trenches in the foundations shall be composed of 15 parts of Portland cement, 45 parts of sand and 110 parts of 1½" ballast, the sand and cement to be thoroughly well mixed before water is added. The concrete used in the hearting of the dam shall be composed of 30 parts of kankar lime, 30 of sand and of 110 of hard sharp stone. If the actual quantities used in the work shall be found to differ from this, the rates will be adjusted accordingly. No stone is to be used in the concrete except such as is approved by the Executive Engineer and is to be perfectly free from sand or dirt and broken to pass through a 1½" ring. The mortar for the concrete is to be hand mixed wet, and the ballast is to be thoroughly wetted before the mortar is added to it, and the whole aggregate is to be well turned over to ensure perfect incorporation upon a close jointed timber or other suitable floor of ample area, and conveniently situated near the site of the works. In no case is the concrete to be tipped or shot, but to be laid in carefully in horizontal layers of nine inches in thickness and to be afterwards rammed with wooden or iron rammers until the mortar flushes evenly at the top.

* This is now made less.

Plums may be used in the concrete, the proportion of plums to be not more than 25 per cent. and the size to be not less than 5 c. ft., but if they are used they must be properly bedded in lime mortar. No concrete or mortar is to be worked up a second time after partial setting nor to be applied to a dry surface Should the weather be dry immediately following the completion of any portion of the work, the concrete or masonry, when sufficiently set, shall be regularly watered in order to prevent the cracking of the surface Any portion that is left for a few days, before work is restarted on it, is to have its surface well swept, picked and cleaned.

270. **Sand.**—The whole of the sand used on the works to be clean and sharp, not over coarse, and, when ordered by the Executive Engineer in charge, to be well washed before use.

271. **Lime and mortar.**—A sample of each batch of lime burnt is to be given to the Assistant Engineer for testing

Each quantity of mortar is to be brought to the same consistency as that previously used, sufficient only being used for immediate requirements, all mortar showing signs of setting before being put into the work to be rejected

272. **Tools and Plant**—The contractor is to provide the whole of the labour, carriage, tools, implements, tackle, legs, staging and all other things requisite for the construction of dam sluice, etc., gantry and tackle necessary for emplacing the sluices will be supplied by Government. If steam pumping is necessary to unwater the foundations of the dam, the pump and engine will be supplied by Government but moved and worked by the contractor at his own expense Government will also provide one mile of tramway and forty trucks for conveyance of materials to the dam, these will be delivered at the canal head and all subsequent expenses including erection and repairs will by borne by the contractor. Government will also provide engines and disintegrators under the same conditions as the tramway

273. **Clearing site dam.**—The contractor shall remove all trees, bushes and clear away all mounds, rubbish and loose earth within the area to be occupied by the dam.

274. **Excavations, Foundations.**—Trenches are to be cut at the upstream and downstream toes, 4'0" broad respectively, of such a depth as to effectually cut out all false seams, springs, veins of soft material, etc, and to such further depths at any part of the foundations as may be found necessary, by the nature of the ground or, as may be ordered by the Executive Engineer. All unsound and weathered portions of the rock between the trenches will be stripped off to the solid to the satisfaction of the Executive Engineer. The cleared foundations must be inspected and approved by the Executive Engineer or other officer deputed by him before any masonry is commenced.

275. **Waste**—The excavated waste from the stripping and trench shall be removed and deposited at such a distance and place as may be indicated by the Executive Engineer or Assistant Engineer in charge. Any of the excavated material which is good enough to be used in the work must be first approved by the Executive Engineer. No deductions will be made from the rates in the schedule on account of the value of any such excavated rock used in the dam.

276 **Materials and workmanship**—The whole of the works, both as regards quality of materials and mode of excavation, must be performed and completed in the most approved, workmanlike and substantial manner, under the direction and to the entire satisfaction of the Executive Engineer or his Assistant.

277. **Royalties**—All royalties to be paid for stone, kankar, etc., will be paid by the contractor and are to be taken as included in the contract rates.

278. **Protection of works.**—Any concrete or masonry which may be loosened or injured during the construction of the work by the passage of floods will be removed and made good, and paid for separately at the schedule rates, but all surfaces which are not injured so as to require removal must be cleaned and prepared for the next season's work at the contractor's expense.

279. **General conditions**—Omission of details on plans, etc.—All the works, although parts of the same only may be marked on the plans and sections, are part of the contract, and included therein, as much as if such works had been particularly set forth and described in the specification also Such of the works as may be mentioned in the specification only, without being drawn on the plans or sections, are included in the contract as if they had been particularly drawn on the plans or sections also, and as there may be details not particularly mentioned in the specification nor drawn in the plans or sections, the contract must be taken to include all such details as may have been omitted, it being clearly understood that the contractor is to execute all the works requisite for the perfect completion of each and every of the several parts according to the true intent and meaning of the specification.

280. **Alterations and Deviations**--The engineer may increase, diminish or alter the work without vitiating the contract, the value of such increases or diminutions or alterations being ascertained from the schedule of rates annexed to the contract, and being added to or deducted from the contract sum, as the case may be.

281. **Temporary huts.**—Should the contractor require to erect temporary huts for his workmen, or other temporary buildings, the sites must be approved of by the Executive Engineer or his Assistant.

282. **Trespassing.**—The workmen are to be prohibited from causing any injury to the neighbouring property, whether in British territory or in Native States, and the contractor is to dismiss at once any workman or foreman so engaged.

283. **Foreman.**—The contractor shall employ at his own cost and charge a competent agent or engineer, who is to be constantly on the work to ensure efficient control and superintendence, and who shall be duly authorised to act and receive instructions from the Engineer or his Assistant, and any instructions given shall have equal validity as if given to the contractor himself. No person shall be employed or allowed to remain on the work or any part thereof who shall be objectionable to the Engineer.

284. **Period of completion**—The entire work shall be completed by the contractor within thirty months of the date on which the foundations are set out, under a forfeiture of one thousand rupees for each week and every week the work shall remain unfinished after the expiration of the period above mentioned. Any delay caused by epidemics shall be allowed for, and the amount of time so allowed shall be fixed by the Executive Engineer.

285. **Disputes**—If at any time during the progress or after the completion of the works any disputes or differences shall arise as to the manner of executing the works, or as to the quality or materials employed, or as to any matter of charge or account between the Executive Engineer and the contractor, they shall be referred to and finally settled by the Superintending Engineer as sole arbiter, whose decision shall be final and binding on both the parties

286. **Payments.**—Payments shall be made at the discretion of the Assistant Engineer in charge and a deduction of 10 per cent. will be made on all bills, the amount deducted forming a security deposit, until it shall have amounted to Rs. 20,000. No material shall be paid for until it is delivered at the site of the work, and then only at rates 25 per cent. below the rates allowed for the material in the schedule.

237. **Progress.**—If at any time during the construction of the work it may appear to the Executive Engineer that the arrangements made by the contractor are insufficient to secure the completion of the work within the period specified, he shall give due notice to the contractor and inform the Superintending Engineer If within one month of the date of the issue of such notice, the contractor fails to complete his arrangements for the completion of the work to the satisfaction of the Executive Engineer, he shall serve the contractor with a notice to close his work and remove his establishment within one month and the Executive Engineer may make whatsoever arrangements appear to him necessary for completing the work. The work actually done by the contractor in such case shall be fully measured by the Executive Engineer or Assistant Engineer on the date on which the contractor removes his establishment, and before the Executive Engineer commences work by other agency. All plant and materials shall be listed and measured up and may be used by the Executive Engineer for the prosecution of the work at rates 25 per cent. below the schedule value in the case of materials, and the plants may be taken over under mutual agreement as to price.

278. **Protection of works**.—Any concrete or masonry which may be loosened or injured during the construction of the work by the passage of floods will be removed and made good, and paid for separately at the schedule rates, but all surfaces which are not injured so as to require removal must be cleaned and prepared for the next season's work at the contractor's expense.

279. **General conditions**.—Omission of details on plans, etc.—All the works, although parts of the same only may be marked on the plans and sections, are part of the contract, and included therein, as much as if such works had been particularly set forth and described in the specification also. Such of the works as may be mentioned in the specification only, without being drawn on the plans or sections, are included in the contract as if they had been particularly drawn on the plans or sections also, and as there may be details not particularly mentioned in the specification nor drawn in the plans or sections, the contract must be taken to include all such details as may have been omitted, it being clearly understood that the contractor is to execute all the works requisite for the perfect completion of each and every of the several parts according to the true intent and meaning of the specification.

280. **Alterations and Deviations**.—The engineer may increase, diminish or alter the work without vitiating the contract, the value of such increases or diminutions or alterations being ascertained from the schedule of rates annexed to the contract, and being added to or deducted from the contract sum, as the case may be.

281. **Temporary huts**.—Should the contractor require to erect temporary huts for his workmen, or other temporary buildings, the sites must be approved of by the Executive Engineer or his Assistant.

282 **Trespassing**.—The workmen are to be prohibited from causing any injury to the neighbouring property, whether in British territory or in Native States, and the contractor is to dismiss at once any workman or foreman so engaged.

283 **Foreman**.—The contractor shall employ at his own cost and charge a competent agent or engineer, who is to be constantly on the work to ensure efficient control and superintendence, and who shall be duly authorised to act and receive instructions from the Engineer or his Assistant, and any instructions given shall have equal validity as if given to the contractor himself. No person shall be employed or allowed to remain on the work or any part thereof who shall be objectionable to the Engineer.

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